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O'Brien & Gere Engineers, Inc.

FORMER POWEREX FACILITY

Willowstick Geophysical Investigation

Final Report

R2-0025040

PHASE II
AQUATRACK®
GEOPHYSICAL INVESTIGATION

Of:

Former Powerex, Inc. Facility

Auburn, New York

For:

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R2-0025041

TABLE OF CONTENTS

FIGURES

i. EXECUTIVE SUMMARY

In 2009, an AquaTrack® geophysical investigation was conducted to help characterize areas of high groundwater porosity and/or preferential flow within the Forge Hollow Member of the Bertie Formation (referred to as the D3 zone). This gypsum-rich bedrock formation—which is highly transmissive and solution enhanced—is located approximately 150 feet beneath the former Powerex, Inc. (Powerex) facility (Site) and dips to the south. Results of the geophysical investigation indicated that groundwater flow within this bedrock unit was more homogeneous than heterogeneous. Nevertheless, four potential preferential groundwater flow paths were identified.

Six bedrock wells were subsequently installed; five wells were located within the four modeled flow paths and one well was deliberately located outside the modeled flow paths for comparison.

A second AquaTrack geophysical investigation was requested to extend the original study area farther to the south. The purpose of the Phase II investigation was to help determine the placement of additional D3 bedrock wells in the extended study area. This report presents the findings of the Phase II work.

A single horizontal dipole configuration was employed to energize the D3 zone beneath the extended study area. The resultant magnetic field information revealed a high degree of homogeneity (even more so than in the Phase I investigation). Nevertheless, some subtle electric current flow paths were identified. A Ratio Response (RR) map and an Electric Current Distribution (ECD) inversion model were created to help identify probable preferential groundwater flow paths in the D3 zone. Figure i (located on the following page) summarizes the findings of the Phase II investigation.

The AquaTrack signature magnetic field, generated from the distribution of electric current flow through the subsurface study area, was measured and used to identify potential groundwater flow paths. A model was created of the subsurface study area predicting the magnetic field response assuming the subsurface to be homogenous. The measured magnetic field data was then divided by the homogeneous model's predicted magnetic field to create a ratio response map (see left map in Figure i). The ratio response map removes electric current bias from the data set and shows areas of greater or lesser conductivity. Areas shaded white (where the ratio is 1:1) indicates where electric current intensity is equivalent to that predicted by the homogenous model. Areas shaded purple indicate areas where electric current intensity is less than predicted by the homogeneous model and areas shaded green represent locations where electric current is greater than predicted by the homogeneous model. It is important to note that the purple shaded areas should not be dismissed. They can provide insightful information showing potential preferential flow paths as revealed by the shape of the contour lines, which is generally more important than the color shading. The purpose of the ratio response map is to accentuate areas where electric current preferentially flows through the subsurface.

The ratio response data was then subjected to an electric current distribution inversion algorithm that predicts the distribution of electric current flow in three-dimensional space. The map on the right in Figure i presents a horizontal slice of the inversion model through the D3 zone.

In reference to the electric current distribution model in Figure i, the light-blue to dark-green shading (going up the scale) identifies increasing levels of electric current density. The dark-blue to purple shading (going down the scale) indicates weak flow of electric current. The black solid lines in both maps identify the center of subtle but potential preferential flow paths or areas where groundwater may concentrate beneath the extended study area in the D3 zone. The thin dashed black line (located in the northeast corner of the maps) is interpreted to be an artifact of a potential groundwater flow path in a shallower unit. This flow path does not occur in the D3 zone.

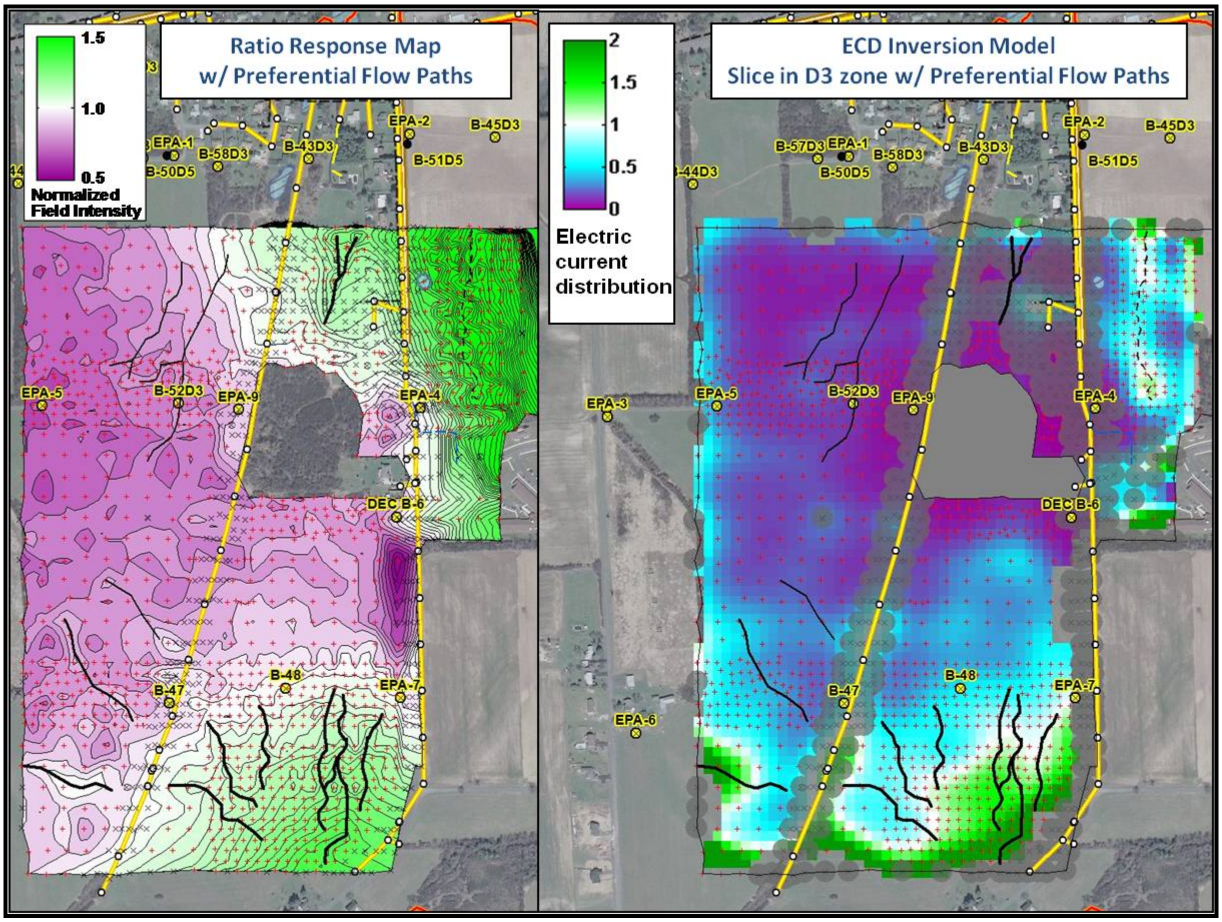

**Figure i – Ratio Response Map (left) and
Electric Current Distribution Model Slice Through D3 Zone (right)**

The information contained in this report can be used by the Owner of the property as well as the engineers and regulatory agencies involved with overseeing the Site in making informed, guided and cost-effective decisions concerning where to place additional monitoring wells in the D3 zone.

1.0 INTRODUCTION

1.1 General

This report presents the findings of a second AquaTrack™ geophysical investigation which was conducted to help identify areas of high groundwater porosity and/or preferential flow within the Forge Hollow Member of the Bertie Formation in an area located south of the former Powerex, Inc. (Powerex) facility (Site) in Cayuga County, New York (located near the City of Auburn – see Figure A).

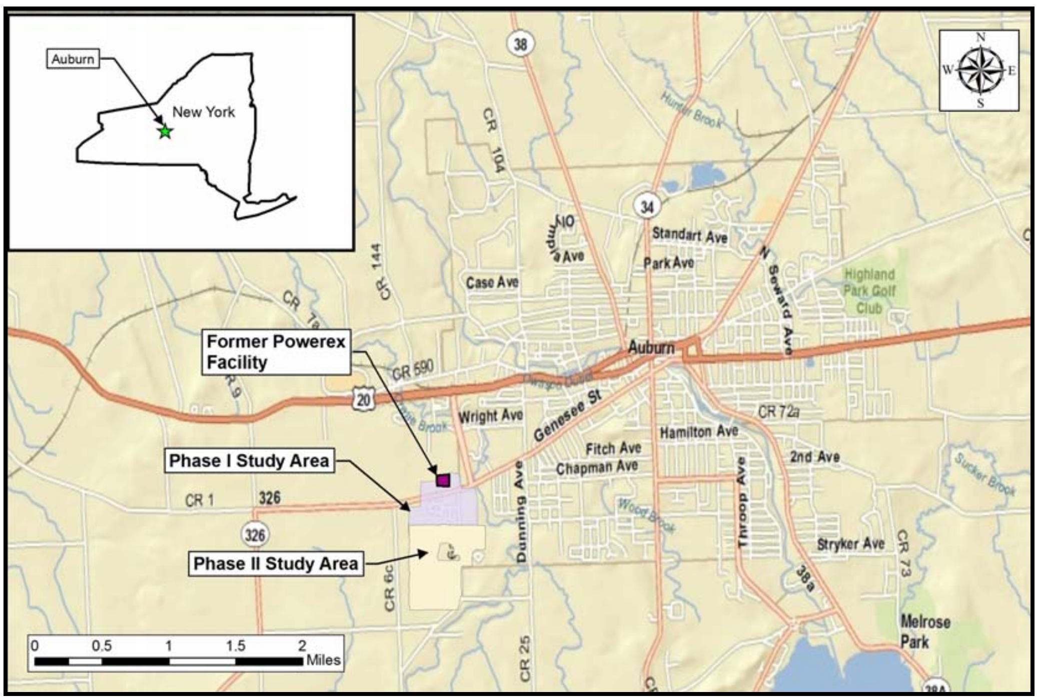

Figure A – Project Location Map

1.2 Background

In 2009, an AquaTrack geophysical investigation was conducted on the southern portion of the Powerex facility and in the residential area located immediately to the south to help characterize areas of high groundwater porosity and/or preferential flow within the Forge Hollow Member of the Bertie Formation (referred to as the D3 zone). This gypsum-rich bedrock formation—which is highly transmissive and solution enhanced—is located approximately 150 feet beneath the Powerex facility and dips to the south. Results of the geophysical investigation and associated Electric Current Flow (ECF) modeling indicated that groundwater flow within this bedrock unit is more homogeneous than heterogeneous. Nevertheless, four potential preferential groundwater flow paths were identified during the Phase I investigation.

Six bedrock wells were subsequently installed; five wells were located within the four heterogeneous ECF modeled flow paths and one well was deliberately located outside of the modeled flow paths for comparison.

A second AquaTrack geophysical investigation was requested to extend the original investigation farther to the south (see Figures A and B). This report presents the findings of the Phase II work.

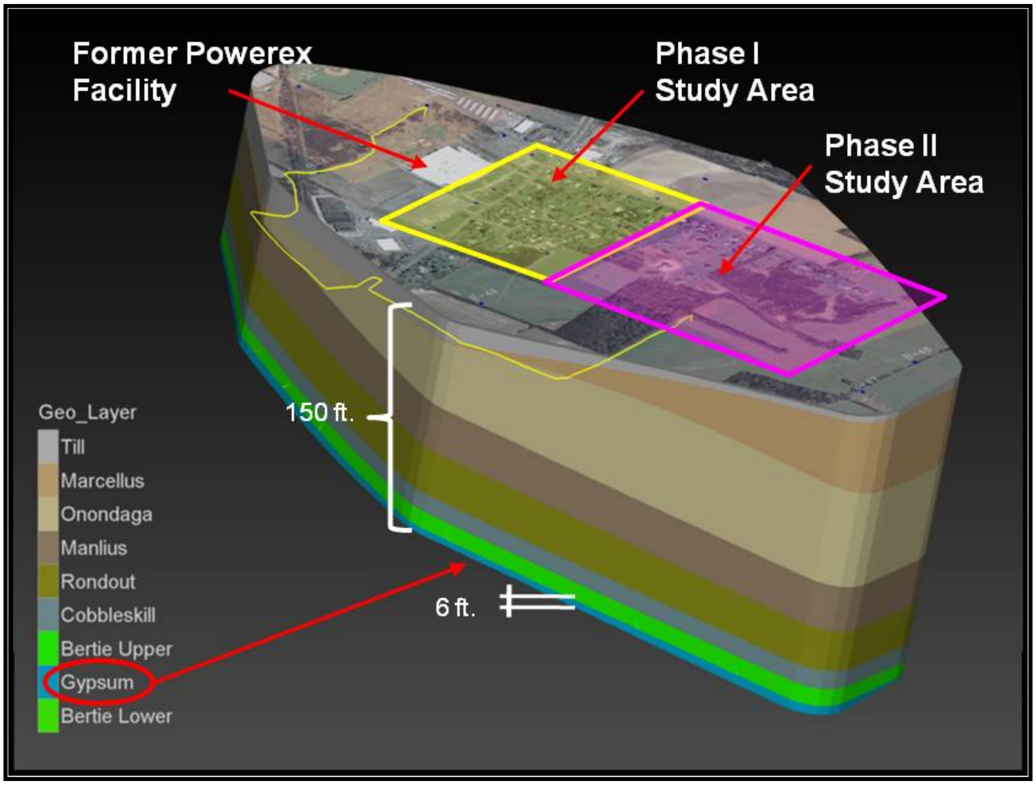

Figure B – Expanded Study Area and Site Geology

1.3 Purpose of Investigation

The purpose of the Phase II investigation is to help determine the placement of additional bedrock wells in the extended study area. The extended study area consists of roughly 175 acres. If potential preferential groundwater flow paths are found in the D3 zone, then these paths are to be mapped and modeled to help characterize groundwater flow beneath the extended study area.

If there are no dominant electric current flow paths (in other words – a uniform distribution of electric current flow through the subsurface study area), then a reasonable conclusion would be that there are no significant preferential flow paths and that the D3 zone is relatively homogenous.

This report presents the results of the Phase II investigation, including how the AquaTrack technology was applied to the extended study area, and also the findings, interpretations and recommendations of the survey. The information contained in this report can be used by the

Owner, its consulting engineers and the regulatory agencies involved with overseeing the project in making informed, guided and cost effective decisions concerning where to place additional monitoring wells to further evaluate and/or monitor groundwater conditions beneath the extended study area.

2.0 AQUATRACK METHODOLOGY

2.1 Explanation of the Technology

O'Brien & Gere Engineers, Inc. (O'Brien & Gere), General Electric Company (GE), the New York State Department of Environmental Conservation (NYSDEC), and the United States Environmental Protection Agency (EPA) are all familiar with the AquaTrack technology as a result of the Phase I work. Nevertheless, if the reader is unfamiliar with the AquaTrack methodology, it is suggested that the reader refer to the White Paper entitled "AquaTrack Technology Explained" in Appendix D. The White Paper presents detailed information about how the technology is used to characterize high porosity zones and/or preferential flow paths beneath the surface of the ground. The application of the technology—as applied in the Phase II work—is similar to that applied for the Phase I work. However, the modeling process is significantly different. Nevertheless, the White Paper can be used as a reference to help explain certain concepts of the exploratory and diagnostic process. See the Table of Contents at the beginning of Appendix D for a quick reference guide to find specific sections of the White Paper that can help clarify certain aspects of the survey and modeling methodology. The modeling process as applied to the Phase II work is explained in detail in the body of the report.

3.0 CONTRACT AND WORK SCHEDULE INFORMATION

3.1 Contract Information

O'Brien & Gere is currently under contract with GE to provide engineering consulting services of which Willowstick® Technologies, LLC (Willowstick) is an approved subcontractor. On September 23, 2009, Willowstick was engaged by O'Brien & Gere to perform an AquaTrack geophysical investigation at the former Powerex facility and the residential area located immediately south of the plant. After completion of this work, Willowstick was issued a change order to extend the study area to the south (referred to herein as the Phase II investigation).

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3.2 Work Schedule

Following the execution of a change order to perform the Phase II work, GE and O'Brien & Gere undertook the responsibility to obtain permission to ingress and egress all properties required for the investigation on both private and public lands (prior to Willowstick's arrival at the extended study area). Figure C shows an ownership map of the study area and those properties where owners either granted or denied access. Permission was successfully obtained from nearly all property owners. Access was denied on a relatively large piece of property located in the center of the extended study area. As a result, field personnel were instructed to work around the perimeter of this property. Although not shown in Figure C, access was also obtained on the public rights-of-way.

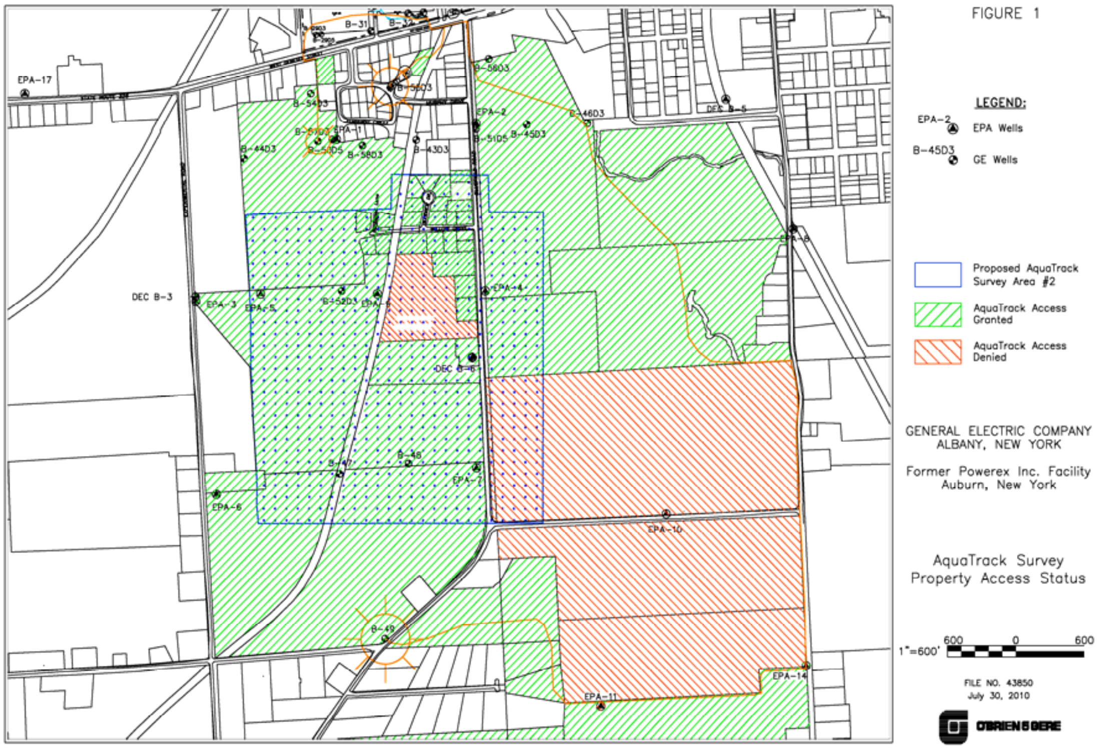


Figure C – Property Ownership Map **(courtesy O'Brien & Gere)**

The Phase II work took roughly three months to complete, including the modeling. The Phase II fieldwork was conducted between July 26 and August 6, 2010. Fieldwork entailed mapping existing culture (e.g., overhead electric lines) pertinent to the survey area, laying out the circuit wire around the study area, placing electrodes in monitoring wells utilized in the investigation, energizing the D3 zone and measuring and recording magnetic field intensities within the extended study area's boundaries. Data reduction, interpretation, modeling and report writing followed the fieldwork.

4.0 APPROACH TO THE WORK

4.1 General

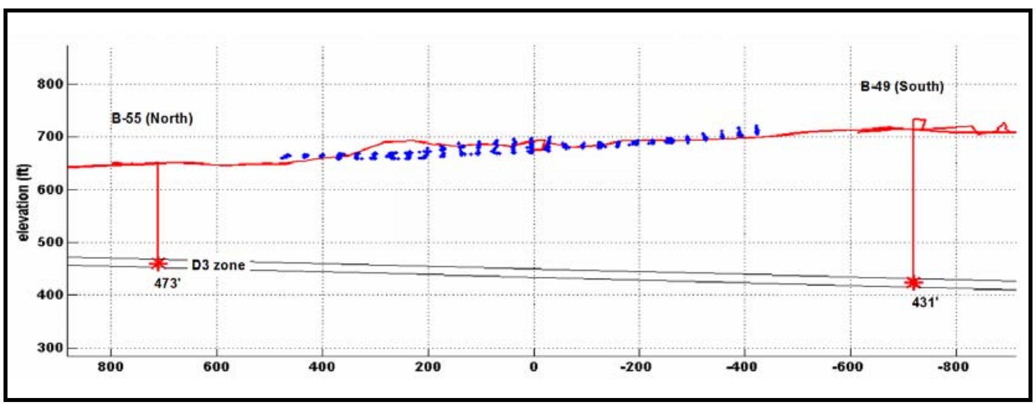
The application of the AquaTrack technology, as applied to the extended study area, is based on the principle that groundwater, found in the D3 zone has considerably higher conductivity than groundwater found in other formations located beneath the study area. The average specific conductivity values for the subsurface zones located above the D3 zone (referred to as zones S, I1, I2, D1 and D2) range from 0.81 to 0.91 Siemens/cm (S/cm). These values were determined from a number of groundwater sampling events as reported by O'Brien & Gere during the Phase I work. The specific conductivity of the D3 zone averages 1.62 S/cm. Based on this information, the D3 zone is estimated to be approximately twice as conductive as the zones above it.

The AquaTrack signature electric current was targeted in the D3 zone by strategically placing electrodes up-gradient and down-gradient of the extended study area in direct contact with the highly ionized groundwater found in the D3 zone. As the signature electric current concentrated and flowed through the highly ionized groundwater regime, surface magnetic field measurements were used to identify the distribution of electric current flow through the D3 zone. The preferential flow of electric current was then used to determine the locations of potential preferential groundwater flow paths.

4.2 Horizontal Dipole Configuration

A single horizontal dipole electrode configuration was used to energize the D3 zone in order to characterize how electrical current aimed and driven through the targeted subsurface study area would flow and react with the conductive groundwater regime.

An up-gradient electrode was placed in a polyvinyl chloride (PVC) cased monitoring well (well B-55D3) that was completed into the D3 zone and located north of the extended study area. A down-gradient electrode was also placed in a PVC cased monitoring well (well B-49D3) which was also completed into the D3 zone but located south of the extended study area. Figure D portrays in cross section the horizontal dipole configuration used in the survey configuration.



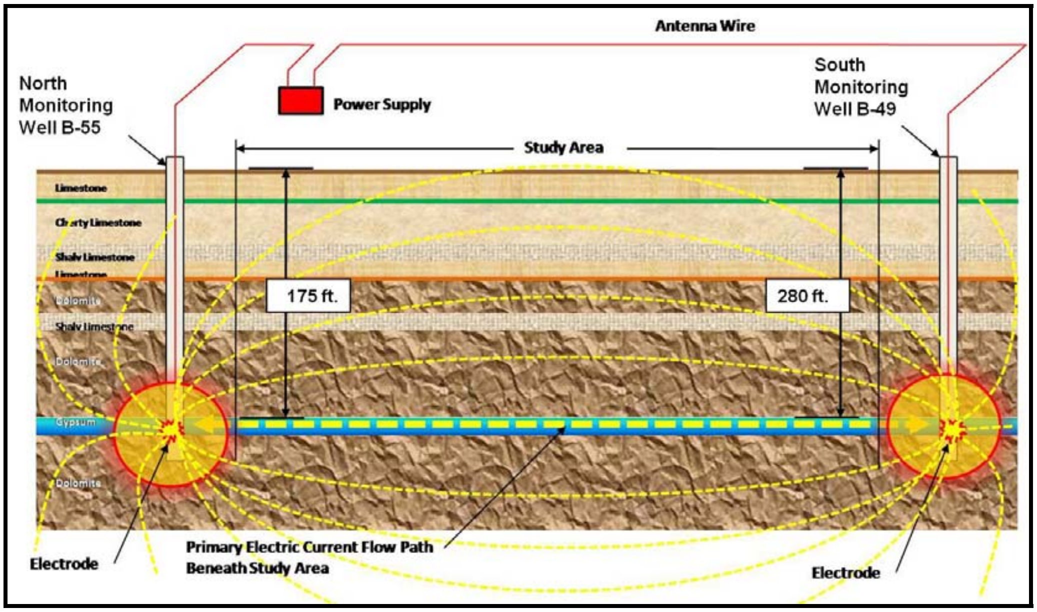


Figure D – Cross Section of Horizontal Dipole Configuration

The overall approach to the horizontal dipole configuration included injecting and biasing an electrical current between paired electrodes located on either side of the subsurface study area and in contact with the highly ionized groundwater in the D3 zone. An alternating current (AC) with a specific signature frequency of 380 Hertz was applied to the paired electrodes. As electrical current flowed between the strategically placed electrodes, it generated a recognizable magnetic field that was measured from the surface of the ground and used to describe the distribution of electric current within the subsurface study area.

4.3 Phase II Survey Layout

A plan view of the survey layout is shown in Figure E.

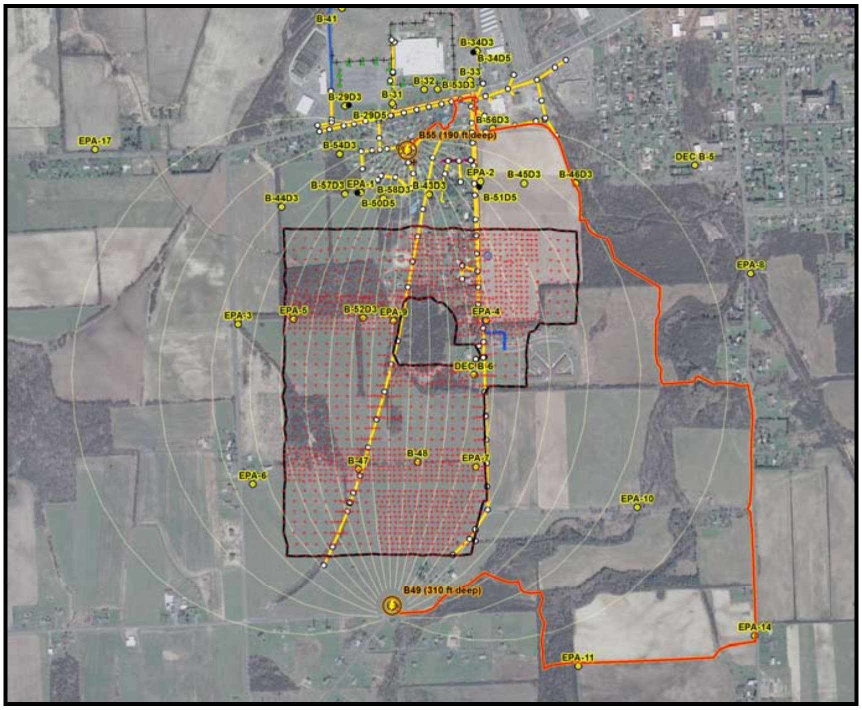


Figure E – Phase II Survey Layout

The black solid line which encompasses the study area includes roughly 175 acres of land. The red circuit wire connecting the strategically paired electrodes (small lightning bolt symbols in the figure) was positioned in a large loop around the area of investigation. These electrodes and the circuit wire are located outside the study area due to the strong magnetic field influence around them. Magnetic field measurement stations are denoted as small red "+" signs or crosses in the figure. Measurement stations were initially established on a 100 foot by 100 foot grid. Additional measurement stations were added on a 50 foot by 50 foot grid where additional detail was warranted and/or requested. An even tighter 25 foot by 25 foot grid was used near overhead power lines to accurately determine the distance away from power lines where measurement stations were unaffected by the signature electric current following along the surface conductors. Measurement station spacing varied slightly depending upon property access, home and/or business locations, safety issues, etc. Many measurement stations were occupied a number of times for quality control purposes. The X, Y and Z coordinates of each measurement station were recorded as part of the fieldwork. These spatial locations are critical to quality control measures, data processing, data interpretation and modeling. The grid density spacing was adequate to obtain sufficient detail and resolution for identifying the distribution of electric current flow through the subsurface study area while at the same time optimizing funds available for the investigation in order to adequately cover the extended study area.

5.0 QUALITY CONTROL

5.1 Quality Control

Quality control is an important aspect of every AquaTrack investigation. Quality control consists of measuring, recording and monitoring the following items:

1. Circuit continuity between electrodes
2. Signal strength and signal-to-noise ratios
3. Signal repeatability
4. Changes in ambient or background noise

Quality control measures employed for the investigation generally indicated clean, consistent and reliable data from which the interpretation of magnetic field intensities were made to determine potential groundwater flow paths. For the Phase II survey, an electric circuit was established with 1.33 amps at 300 volts. The median margin of error for measurement station readings was 7.4% (meaning that consecutive readings were repeatable to within 7.4% of the measured value). The circuit continuity, magnetic field signal strength, and signal-to-noise ratios for the survey indicated quality data. The noise floor (mean ambient field noise, determined from a sampling of several frequencies in the noise spectrum) remained low and constant throughout the investigation. Numerous measurements were repeated throughout the course of the fieldwork, all of which indicated clean, consistent and reliable data. For further details regarding quality control measures see Appendix B.

6.0 DATA REDUCTION AND MAGNETIC FIELD CONTOUR MAPS

6.1 Data Processing and Correction

The analysis of the magnetic field data entailed reduction of magnetic field measurements to processed and corrected data sets ready for interpretation. The data sets were subject to a number of comparisons and corrections to account for: 1) differences between instruments used in the investigation; and 2) atmospheric noise (diurnal magnetic variations, magnetosphere activity, etc.). Once the data set was reduced and/or normalized, the data set was analyzed by generating a magnetic field contour map of the processed and corrected data.

A geo-referenced aerial photograph of the extended study area was used as a base map for presenting the results of the investigation. Some features critical to the investigation have been drawn on top of the aerial photograph to enhance their presence and to supplement the information contained on the base map.

6.2 Phase II Magnetic Field Contour Map

Figure F presents the resultant magnetic field contour map created from the injected electric current in the D3 zone between wells B-55D3 and B-49D3. This magnetic field contour map is referred to as a “footprint map” because it reveals areas of high and low electrical current flow across and beneath the study area. Keep in mind that the full-sized figures found in the Figures Section of this report include complete legends and color scales for all maps. Appendix A provides additional information with regard to interpreting magnetic field footprint maps.

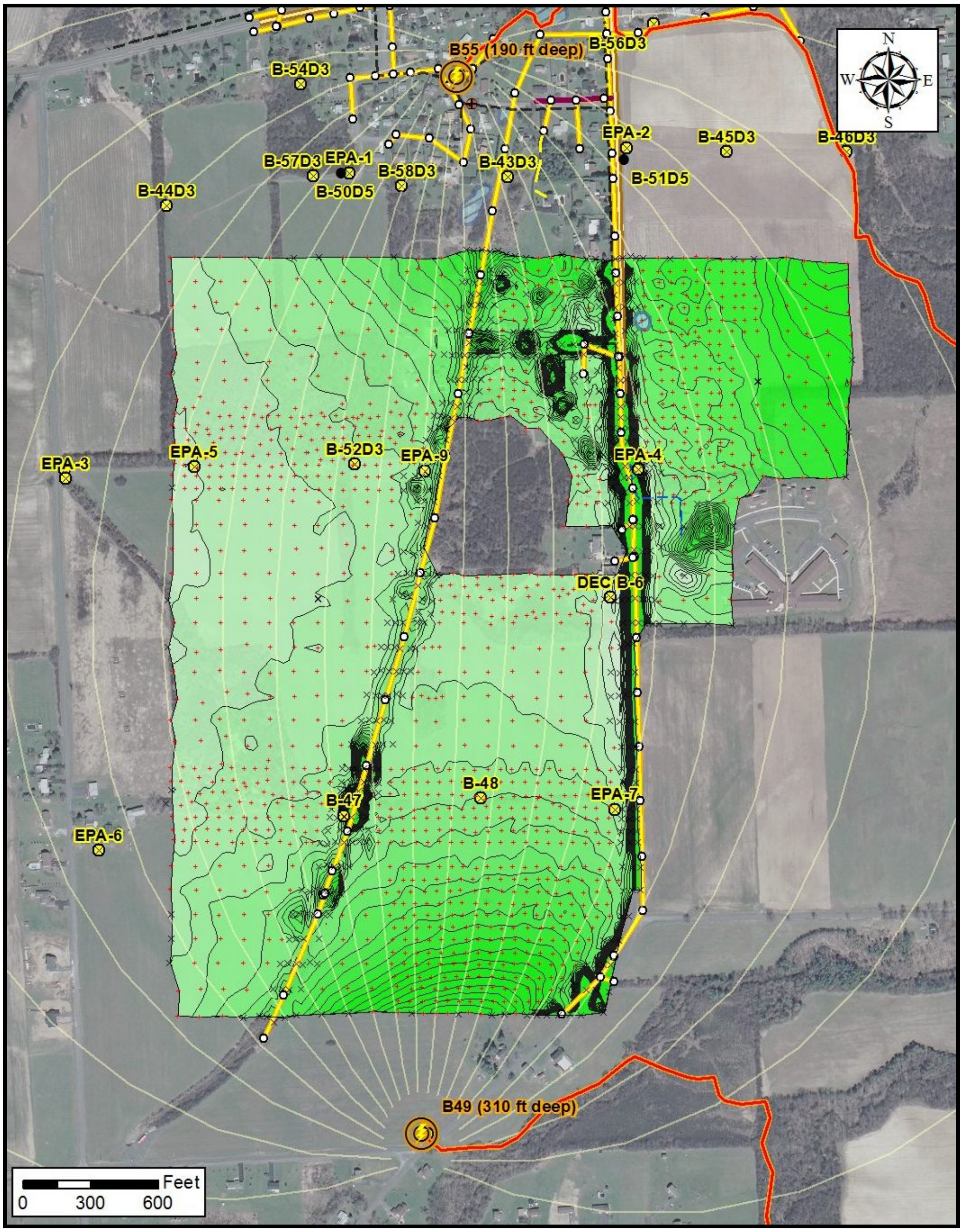


Figure F – Phase II Magnetic Field Contour Map

In order to interpret this map, it is important to keep in mind that in general there are **three** strong influences that affect the subsurface electric current flow. They are: 1) ionized groundwater; 2) conductive cultural features; and 3) electric current bias. These are described below.

1. The technology is based on the principle that its signature electric current is strongly influenced by the presence of ionized groundwater and areas of higher effective

porosity where the ionized groundwater can accumulate and/or flow relatively freely. The electrical current will naturally gather and concentrate in areas or pathways of higher conductivity.

2. The magnetic field may be influenced by culture, which is any conductive man-made feature such as pipelines, power lines, utility tracer wires, steel fence lines, or other long continuous conductors. Culture is often present, and can be very problematic because it tends to be near-surface and can cause large anomalies that hide some of the magnetic signal coming from the subsurface. There are two power lines that cross over the extended study area. These are denoted as yellow lines with white dots in the figures. The yellow lines represent power line locations and white dots represent power pole locations. The best approach when surveying an area with conductive culture is to identify the conductive features before a survey is initiated and then strategically design the survey to avoid, to the extent possible, any long conductive feature. As with the Phase I work, electrodes were placed at depth in the D3 zone, which is more than 150 feet below ground. Nevertheless, electric current was observed flowing onto near surface conductive culture (see Figure F). Fortunately, the location of the majority of conductive culture is known. The influence of near surface conductors was removed and taken into account when interpreting the data. This will be explained later in this report.

3. The magnetic field in any given survey is always subject to electrical current bias because electric current must travel from one electrode to the other in order to complete the circuit. The variable part of the circuit—and the interesting part—is what happens to the electric current when it is allowed to choose its own paths to flow between electrodes. It is always true that 100% of the electric current must concentrate in and out of the points of coupling (the electrodes), and hence the magnetic field tends to grow much stronger as it nears these points. The magnetic field effect from this part of the circuit can be predicted and removed from the data set. The variable part of the circuit—and the interesting part—is what patterns of electric current distribution occur aside from the electric current bias and other predictable behavior. These patterns tend to emerge more fully when the predictable but unwanted portions of the magnetic field are removed.

*In order to properly interpret the magnetic field data, it is critical that these three influences be identified and separated out as part of the interpretive process***.** This is sometimes more easily said than done, but fortunately, the culture and the electric current bias are more predictable than groundwater flow patterns. Figure F shows all of the data prior to the removal of any of the mentioned effects, which processes are described following this section. Once removed, the next step in interpreting the distribution of electric current flow through the subsurface is to separate out near surface interferences and identify anomalies that reveal electric current flow patterns related to potential preferential flow in the D3 zone and to build an interpretation and model of potential groundwater flow based on the concentration of electric current flow through the subsurface study area.

7.0 REMOVAL OF NEAR SURFACE INTERFERENCES

7.1 Criteria to Distinguish Near-Surface Interference

As experienced while performing the Phase I work, the Phase II work also exhibited signs of electric current straying onto near-surface power lines. It was therefore necessary to remove near surface interference in order to properly interpret the distribution of electric current flow in the subsurface. Near-surface interferences and/or measurement stations determined unreliable are distinguished by four quality control criteria:

1) Signal-to-noise ratios
2) Normalized gradient filter
3) Distance from culture
4) Point-specific professional judgment

These four criterions were applied to the data set to identify measurement stations determined unreliable. The number, location and reason measurement stations were removed from the original data set are described in Appendix B.

7.2 Filtered Phase II Magnetic Field Contour Map

Figure G below presents the filtered magnetic field map after having applied the quality control measures describe in Appendix B. Stations that passed the quality control measures are shown with red crosses ("+" signs) in the figures. No measurement station was removed as a result of a poor signal-to-noise (criteria #1). Stations removed after criterion #2 and #3 were applied (normalized gradient filter and distance-from-culture cutoff) are shown with an "x" in the figure. Stations removed by professional judgment (criteria #4) are shown with a circle around the "x". A very small percentage of the measurement stations were removed through the point-specific professional judgment criterion.

Table 1 presents the total number of measurement stations recorded for the Phase II survey and the number of stations removed based on each quality control criterion. Some were removed for more than one reason. Although only 70% of the measurement stations remained in the data set, this is somewhat misleading because of the extra measurement stations taken near power line corridors—which were obtained to better estimate distance-from-culture cut-off criteria.

Survey #	Total Measurement Stations	Criteria #1: Low Signal-to-Noise	Criteria #2: Gradient Filter	Criteria #3: Distance from Culture	Criteria #4: Professional Judgment	% of Points Kept
Phase II	1,746	0	420	92	6	70

Table 1 – Points Removed by Quality Control Measures

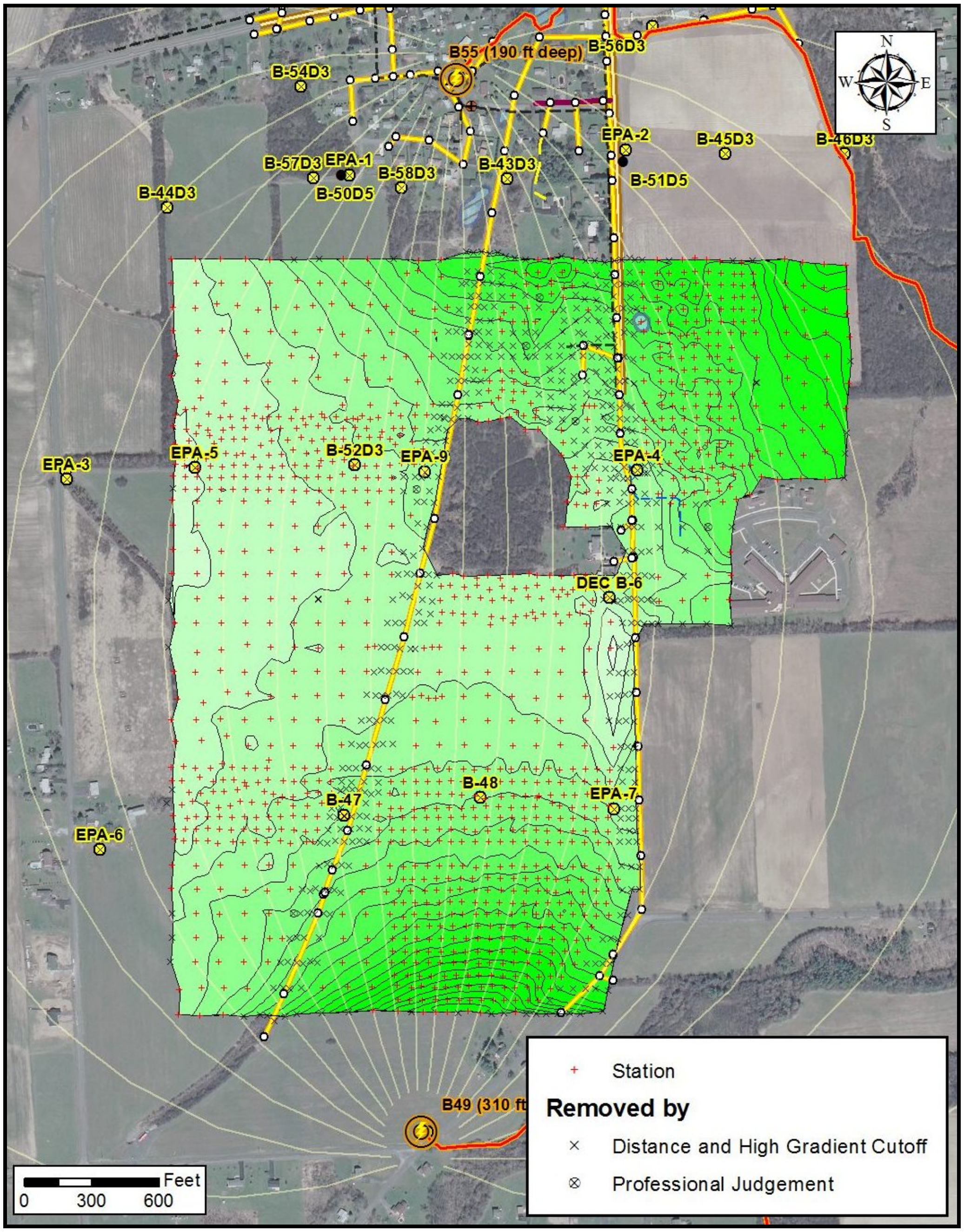


Figure G – Filtered Phase II Magnetic Field Contour Map

The filtered magnetic field contour map is not significantly different from the raw magnetic field map. The most important observation from this map is that the subsurface appears more homogenous than heterogeneous. This was also observed in the Phase I investigation. This will be explained later in the report.

8.0 PREDICTED MAGNETIC FIELD CONTOUR MAP

8.1 Predicted Magnetic Field Response

In order to more scientifically identify areas of greater or lesser conductivity through the extended study area, a model was created which predicts the magnetic field response expected at each survey measurement station given the position of the circuit wire and location of electrodes under the assumption of a homogenous subsurface (see Figure H).

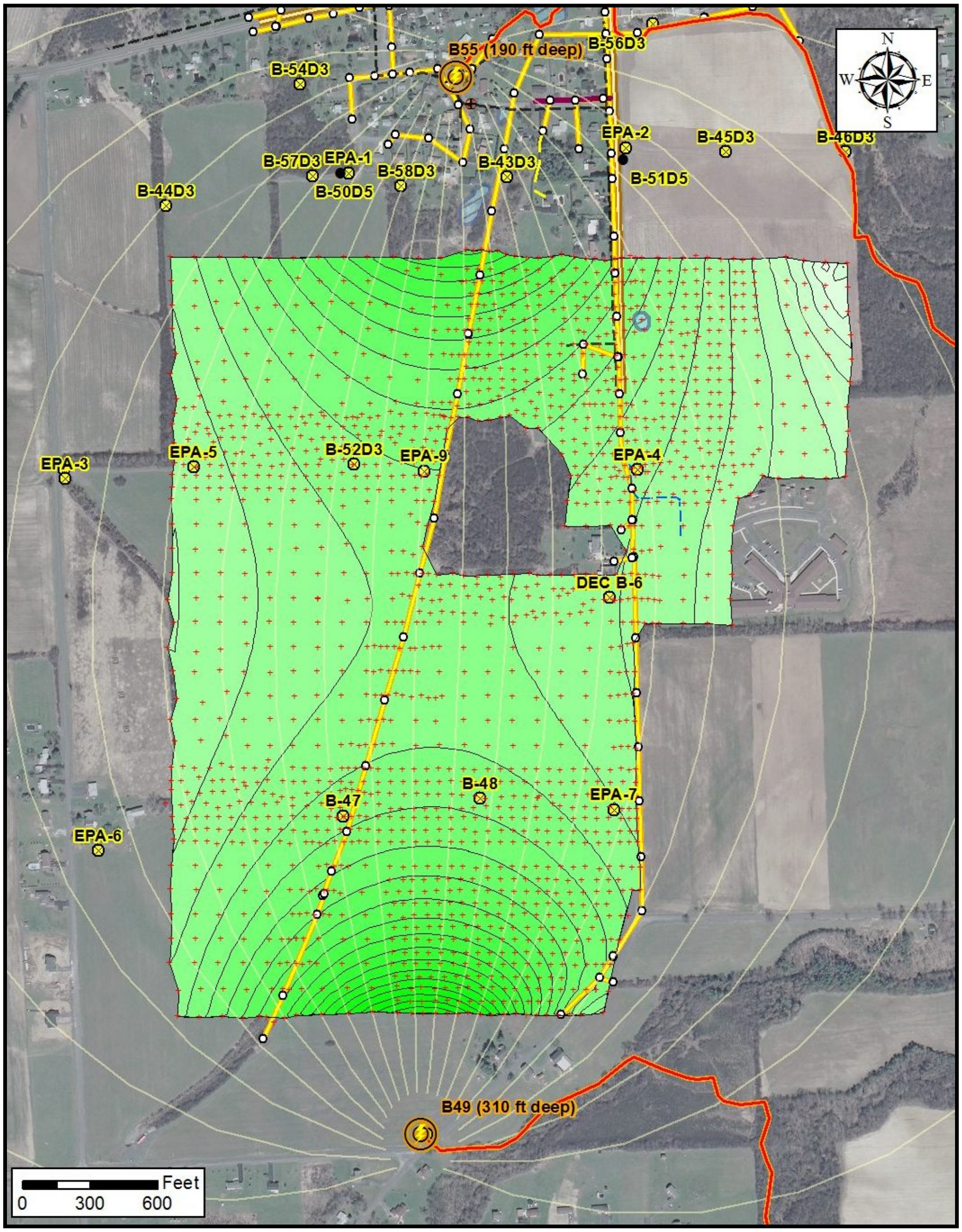


Figure H – Predicted Magnetic Field Map

The predicted magnetic field is based on a homogeneous half-space model wherein topography is approximated by a planar surface; as a result, the model does not account for the slight topographic changes that occur within the study area. This does not invalidate the interpretation of the data. The distortion is not expected to be significant. This is because the extended survey area is relatively flat.

When comparing the filtered magnetic field with the predicted magnetic field, both maps look very similar (see Figure I). One notable difference between the two maps occurs in the northeast corner of the extended study area.

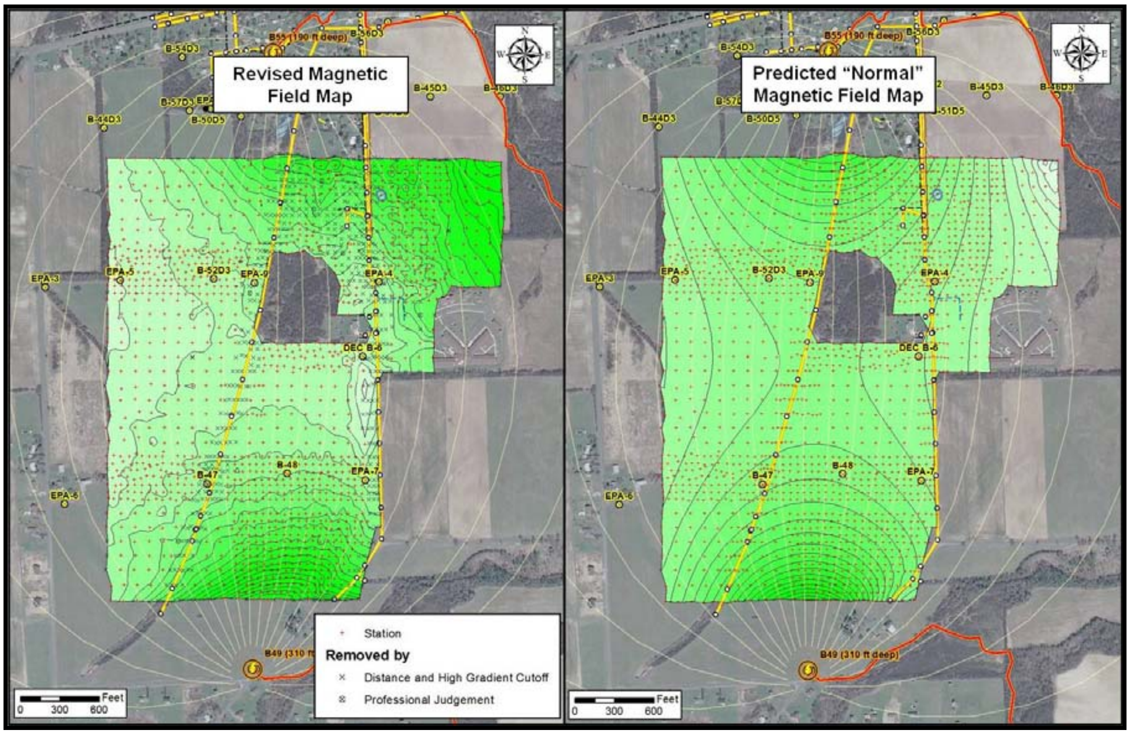


Figure I – Side-by-Side Comparison of Magnetic Field Map and Predicted Magnetic Field Map

The magnetic field intensity in the northeast corner of the magnetic field map (left) is much stronger than predicted (right). It is important to note the location of the circuit wire in relationship to the northeast corner of the study area. Because of its close proximity to the study area, the circuit wire appears to be influencing measurement stations in this area. This will be further discussed in the next section of the report.

9.0 RATIO RESPONSE MAP

9.1 Ratio Response Map

In order to enhance areas of greater or lesser conductivity through the extended study area, the filtered magnetic field map (Figure G) was divided by the model's predicted magnetic field map

(Figure H). As a result, a ratio response (RR) map was created (see Figure J). This map removes electric current bias created from the locations of circuit wire and electrodes and shows areas of greater or lesser conductivity than that predicted by the model.

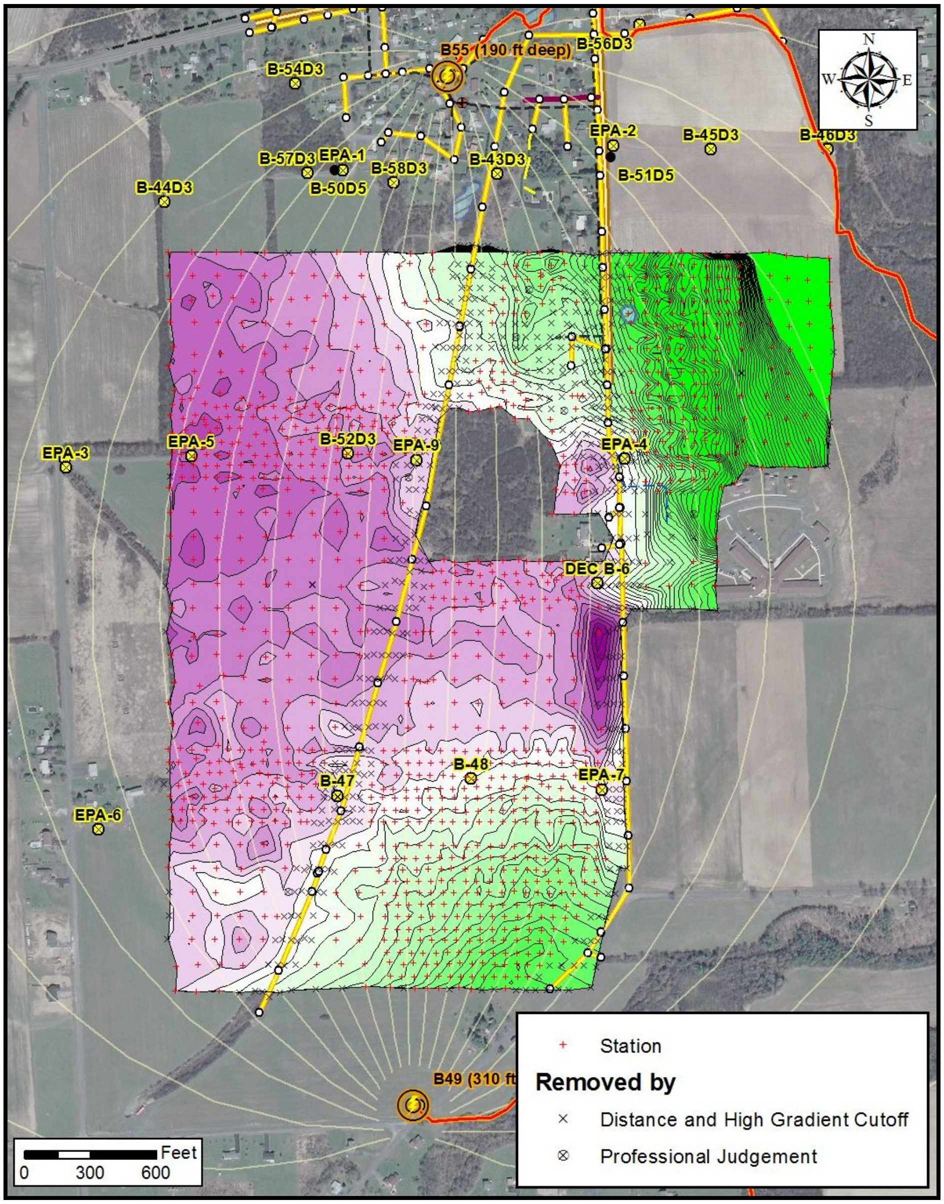


Figure J – Ratio Response Map

The white shaded portions of the RR map (where the ratio is approximately 1:1) represents areas where the electric current intensity is equivalent to that predicted by the homogeneous model. Areas shaded purple indicate areas where electric current flow is less than that predicted and areas shaded green represent locations where electric current flow is greater than that predicted by the model. It is important to emphasize that purple shaded areas should not be overlooked. They can provide insight that can help identify potential preferential flow paths as revealed by the shape of contour lines, which is more important than color.

R2-0025061

9.2 Secondary Magnetic Field Effects

One important purpose in generating an RR map is to remove the influence of the primary magnetic field created from the flow of electric current in and out of the electrodes and along the circuit wire. In Figure J, and as mentioned in the previous section of the report, the RR map shows a strong magnetic field response in the northeast corner the extended study area. This magnetic field appears to be radiating from the circuit wire. Note how the dark green shaded contour lines are uniformly spaced and parallel to the circuit wire in Figure I. This strong magnetic field is not believed to be a result of the primary magnetic field. As mentioned, the RR map removes this effect. Rather, the strong magnetic field is believed to be the result of secondary eddy currents that are induced in the ground as a result of the primary magnetic field (see Figure K).

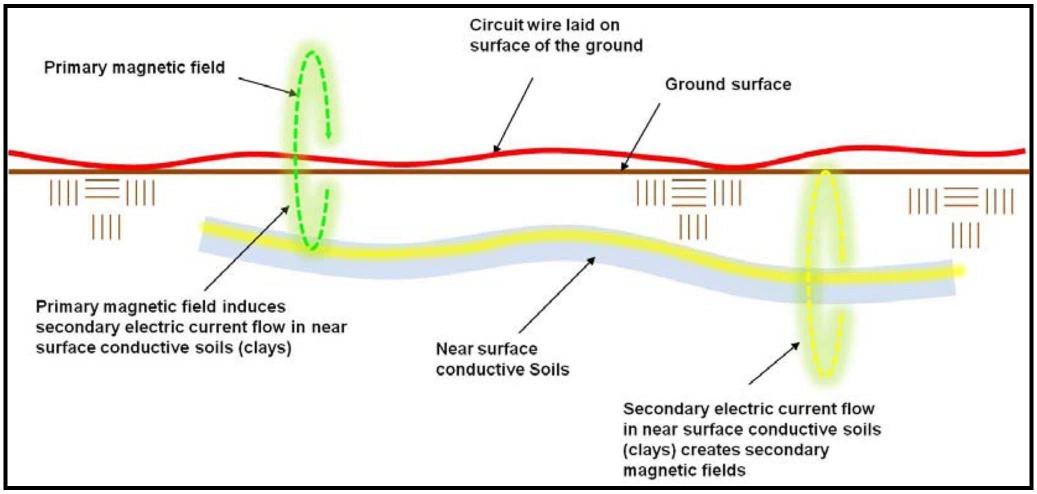


Figure K – Secondary Magnetic Field Effects

Because secondary magnetic fields cannot be predicted, they cannot be removed in the RR map. This is why the circuit wire is placed outside and away from the study area. As a general rule of thumb, the circuit wire is normally placed three times the distance of the depth of the targeted subsurface zone of interest away from the study area (3 x 150 feet or roughly 450 feet). Originally, the study area maintained this buffer zone. However, after initial data was gathered, the survey was extended to the east because an anomalous feature was observed on the northeast edge of the study area. This was done even though the survey extended into the buffer zone. Nevertheless, and as will be explained, some insightful information was gathered from extending the survey to the east.

One other point of interest that should be noted was that the near surface soils contain a significant amount of clay. Wet clay is relatively conductive and can enhance secondary eddy currents. Although secondary magnetic field effects are observed in the data in the very northeast corner of the extended study area, they do not negatively impact the results of the overall investigation.

R2-0025062

10.0 PRE-MODELING INTERPRETATION

10.1 Comparison of RR Map and Magnetic Field Contour Map

One important aspect in identify anomalous magnetic field patterns in a relatively homogenous environment is that anomalous features must show up along a number of adjacent magnetic field contour lines and be defined by several measurement stations. This applies to both the magnetic field map as well as the ratio response map. An old but potentially useful example of this type of analysis is that of mapping linear features on aerial photographs. When looking for yield in a study area, drillers might "gain an edge" by locating supply wells at the intersections of significant photo liners. Figure L presents a side-by-side comparison of the magnetic field map and RR map wherein linear features were identified and noted.

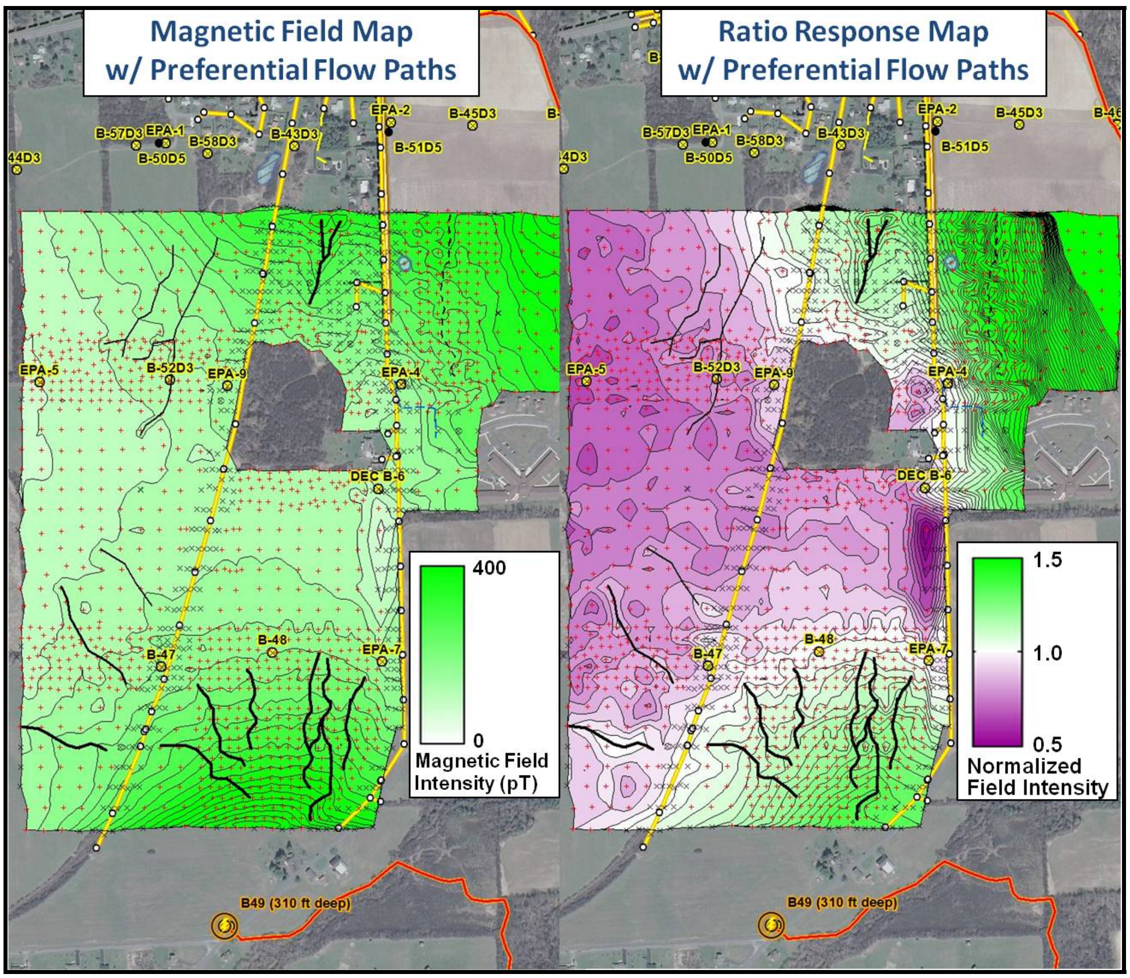


Figure L – Comparison of Magnetic Field Map and Ratio Response Map

The black lines in the maps identify linear anomalous features observed in both data sets. These lines were defined from at least three magnetic field contour lines as well as from several measurement stations. Even though the distribution of electric current is relatively homogenous, the black lines identify subtle preferential flow paths or areas where electric current is slightly more concentrated.

Throughout the central and western half of the extended study area (shaded purple in the ratio response map), electric current is weaker than predicted. In these areas, the magnetic field is relatively uniform as evidenced by sparsely spaced contour lines. This would indicate a uniform distribution of electric current with little change in electrical properties.

Even though the northeast corner of the study area is influenced by secondary magnetic field effects, an anomalous feature is noted in this area. This anomalous feature is noted by a thin black dashed line rather than a solid black line because of the secondary magnetic field effects.

11.0 MODELING

11.1 Modeling Methodologies

The magnetic field map and ratio response map are provided to identify the horizontal distribution of electric current flow through the subsurface study area. It is much more difficult to determine with any degree of accuracy the vertical distribution of electric current flow because the magnetic field can only be measured from the surface of the ground. As a result, modeling was employed to help estimate the vertical distribution of electric current flow.

Willowstick has developed two modeling methodologies used to identify the horizontal and vertical distribution of electric current flow through the subsurface. One consists of a channel flow or ribbon model (termed Electric Current Flow [ECF] model). This type of model was employed in the Phase I work and consists of finite elements comprising paths which have varying widths and depths (like short little ribbons connected together). The ribbon model represents the spatial location of where electric current concentrates in the subsurface. Modeling is accomplished by simulating electric current flow along these ribbons to generate a theoretical magnetic field response at each and every surface measurement station surrounding the ribbon. The depth of the flow path can be modified and adjusted until the model produces a magnetic field response that compares with that measured in the physical data. This type of model requires well-focused or well-defined anomalous features to yield accurate results.

Because electric current in the Phase II study flows more homogenously than heterogeneously (even more so than in the Phase I study), the ribbon method could not be used to model the results due to the low contrast or rather flat gradients. For this reason, the RR data was subjected to an inversion algorithm designed to predict the distribution of electric current flow in three-dimensional space (based on the accentuated RR magnetic field data). This type of model is referred to as an Electric Current Distribution (ECD) model. Figure M presents horizontal and vertical slices through the ECD model created for the extended study area.

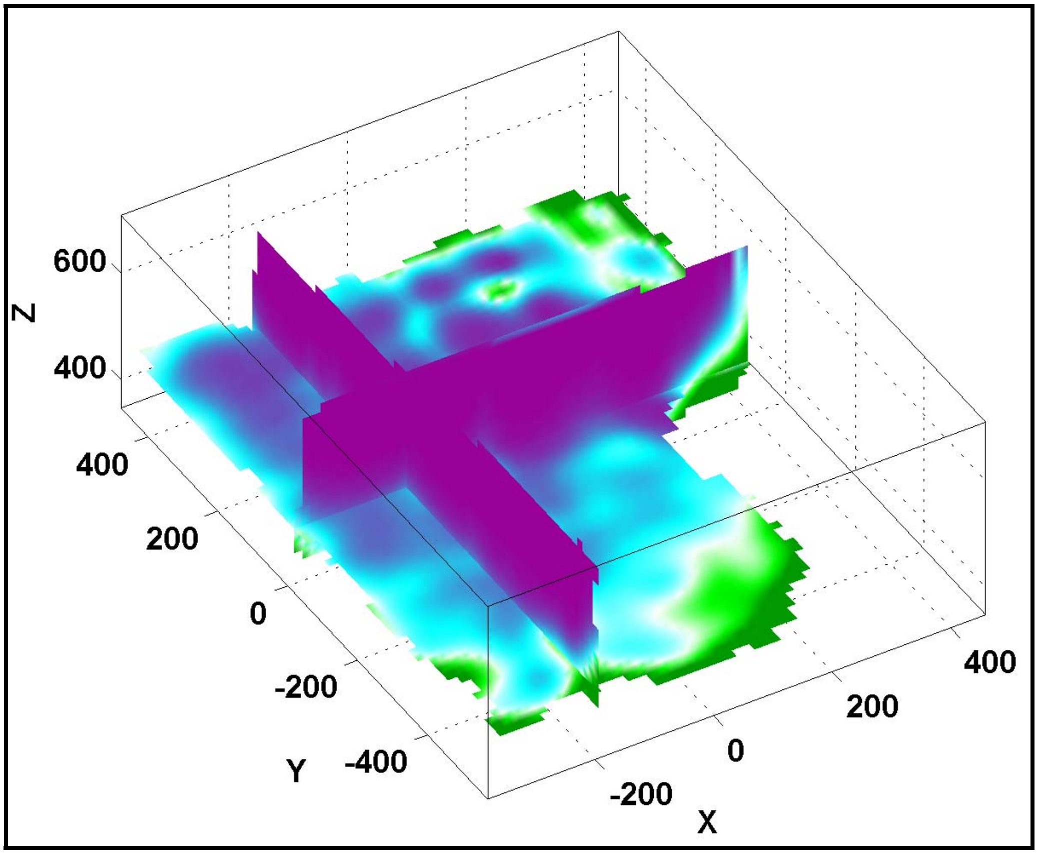


Figure M – Three Dimensional View of Electric Current Distribution (ECD) Model

In Figure M, the green shading identifies areas of higher conductivity where electric current is believed to be more concentrated. On the other end of the color scale, the purple shading identifies areas of lower conductivity where electric current is observed to be less concentrated.

Willowstick uses MATLAB software to generate and analyze ECD models in the form of volume data. The model viewer can generate slices at any elevation or cross-section position within the volume (as the example above shows). Because unlimited slices and views can be created, it is beyond the scope of this report to show all possible slices of interest.

11.2 Electric Current Distribution Model

To summarize the more notable findings of the investigation, Figures N through Q were created. Each figure presents a slightly different view of the ECD model in order to describe how electric current preferentially flows in and around the D3 zone. Figure N presents a horizontal slice taken 40 feet above the D3 zone. The slice in Figure O is taken 20 feet above the D3 zone. Figure P is taken through the D3 zone, and the horizontal slice in Figure Q is taken 20 feet below the D3 zone.

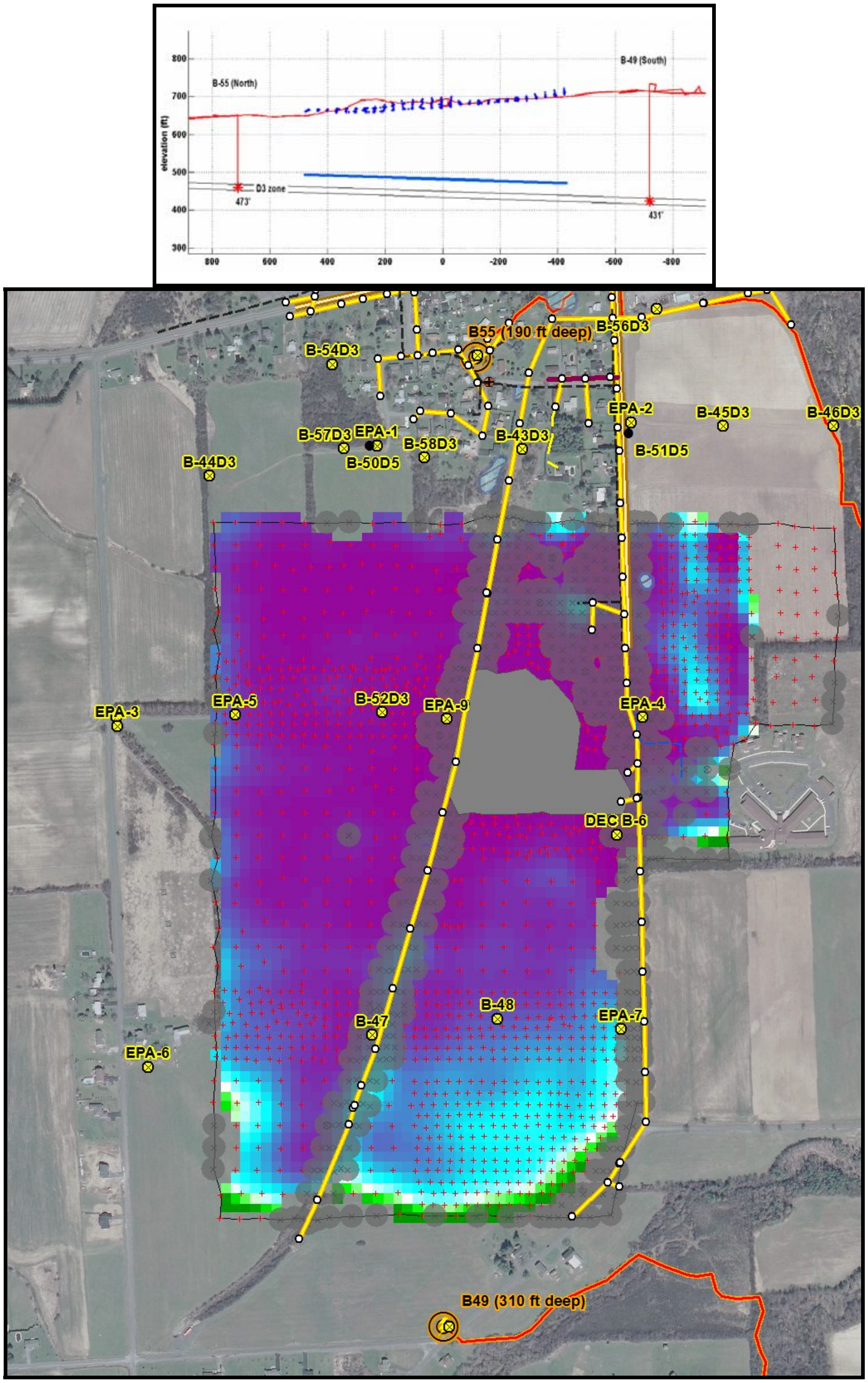


Figure N – ECD Model Slice Taken 40 Feet Above D3 Zone

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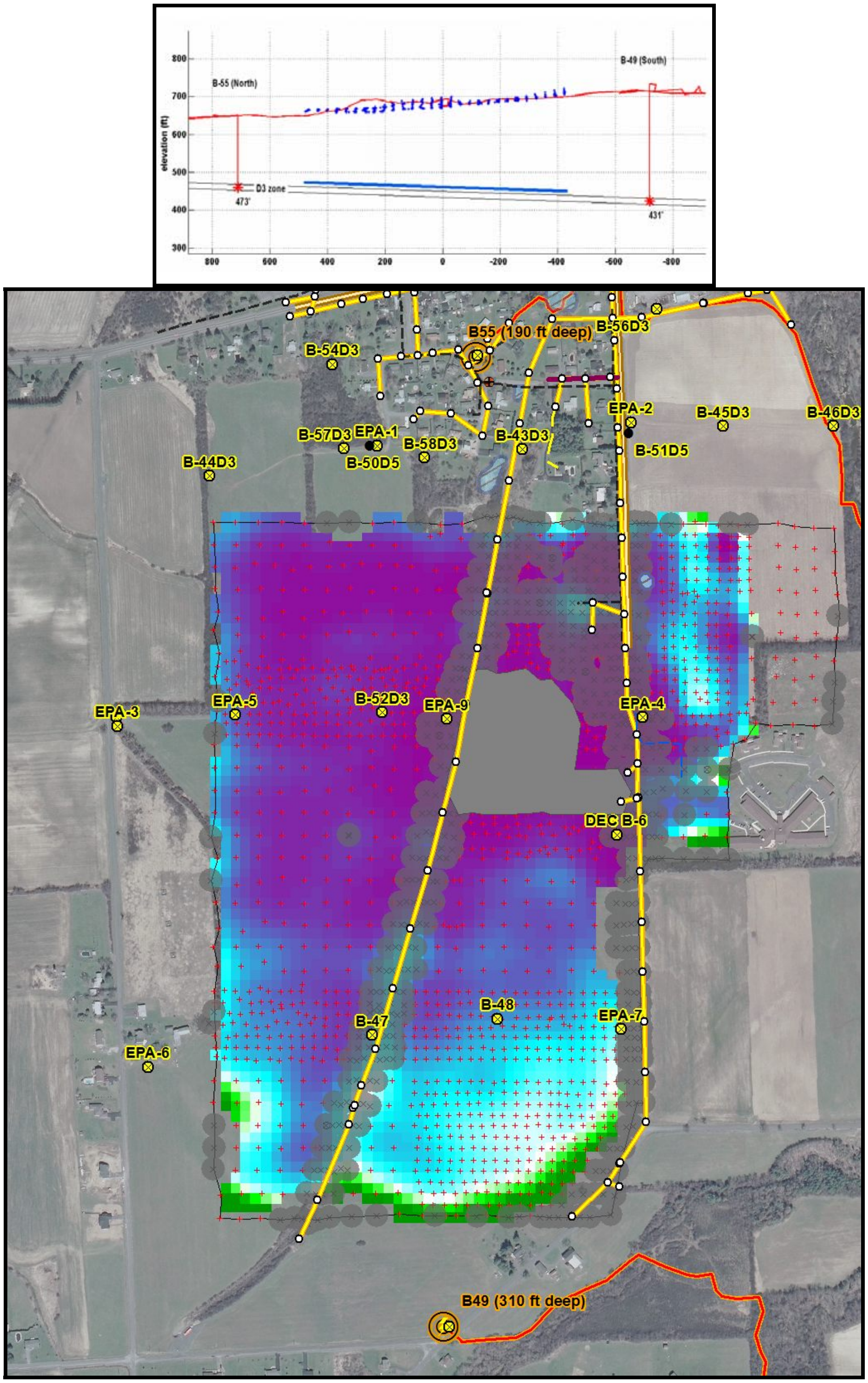

Figure O - ECD Model Slice Taken 20 Feet Above D3 Zone

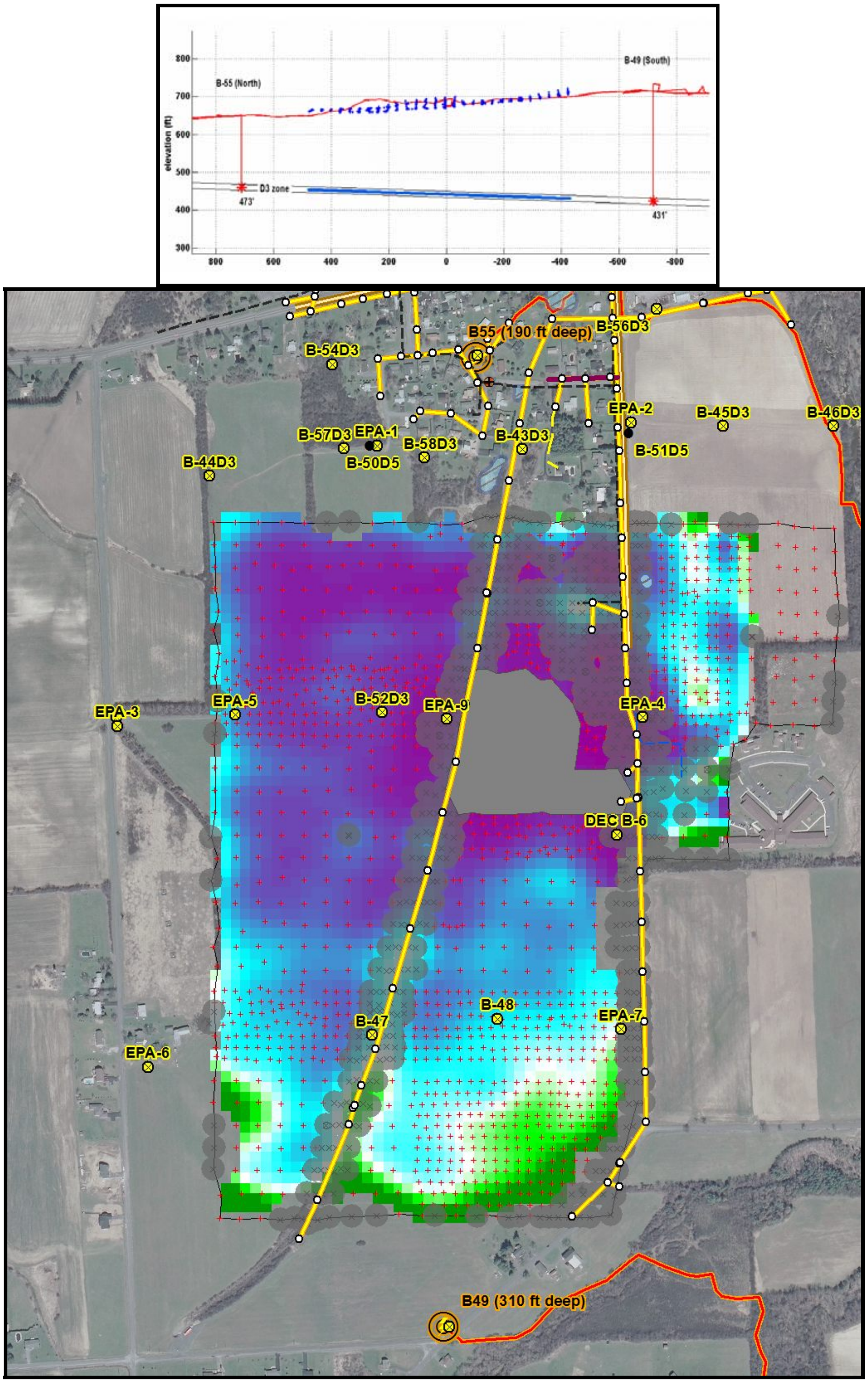

Figure P - ECD Model Slice Taken Through D3 Zone

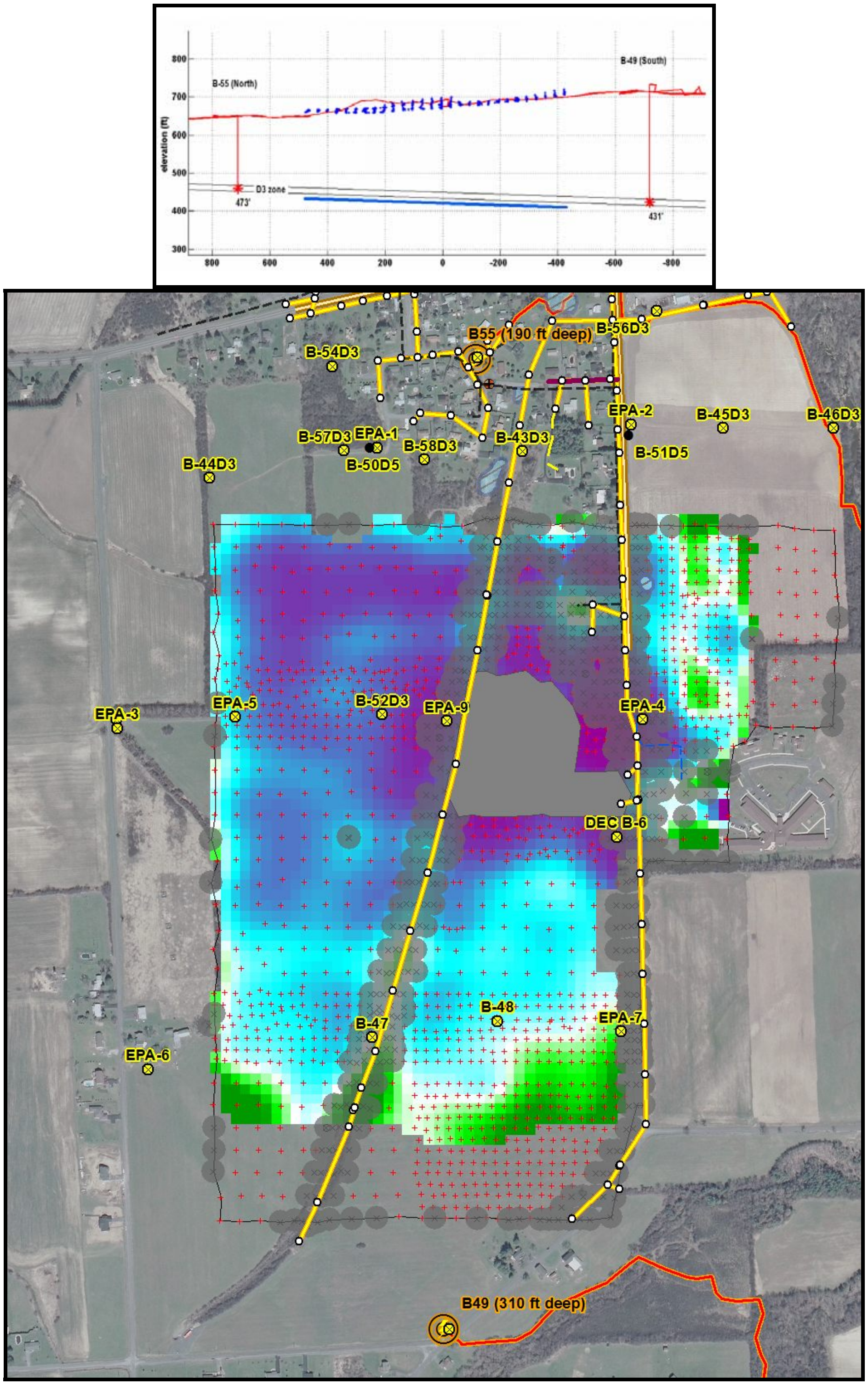

Figure Q - ECD Model Slice Taken 20 Feet Below D3 Zone

11.3 Possible Flow Paths Above the D3 Zone

In Figure N, which is taken 40 feet above the D3 zone, the most notable flow path occurs in the northeast corner of the study area. This anomaly (identified by its light blue shading) runs north to south and is first observed in the model near the surface of the ground. When an anomalous feature is relatively shallow and broad (more so than a typical cultural feature like a pipe line, power line, wire, steel fence, etc.) it can sometimes trick the inversion program by extending the anomalous feature deeper into the subsurface than it actually is—similar to casting a shadow down through the model. Therefore, because this anomalous feature is first observed near the surface of the ground, this anomaly is more likely an artifact of a shallower groundwater flow path. Therefore, this flow path does not likely occur in or near the D3 zone.

The majority of the map in Figure N is shaded mostly dark purple, suggesting that electric current flow in this horizon above the D3 is relatively weak and uniform. There are some anomalous features around the edges of the model. Caution should be used when interpreting data near edges of the model. Edges do not have measurement stations beyond the study area. Thus, unusual edge effects are often observed. The only other observation made from this horizontal slice is the light blue shading in the southeast corner of the study area near the southern electrode. This area is slightly more conductive but still relatively uniform. There are no other well-defined or notable preferential flow paths observed in this horizon.

As one progresses down in elevation through the model toward the D3 zone (see Figure O), the subsurface appears to be increasing in conductivity. This is expected given the D3 zone is twice as conductive as the zones above the D3 zone. Although the subsurface appears slightly more conductive, there are no well-defined flow paths noted other than that in the northeast corner of the study area which is interpreted to be an artifact of a shallower electric current flow path.

11.4 Possible Flow Paths Observed in D3 Zone

Figure P shows the results of the inversion model taken through the D3 zone. Although there are no well defined flow paths at this horizon, there are some subtle areas where anomalous features are beginning to emerge from the data. Figure R presents a side-by-side comparison of the RR map and the ECD model taken through the D3 zone. The subtle but potential flow paths earlier identified are traced onto the horizontal slice through ECD model.

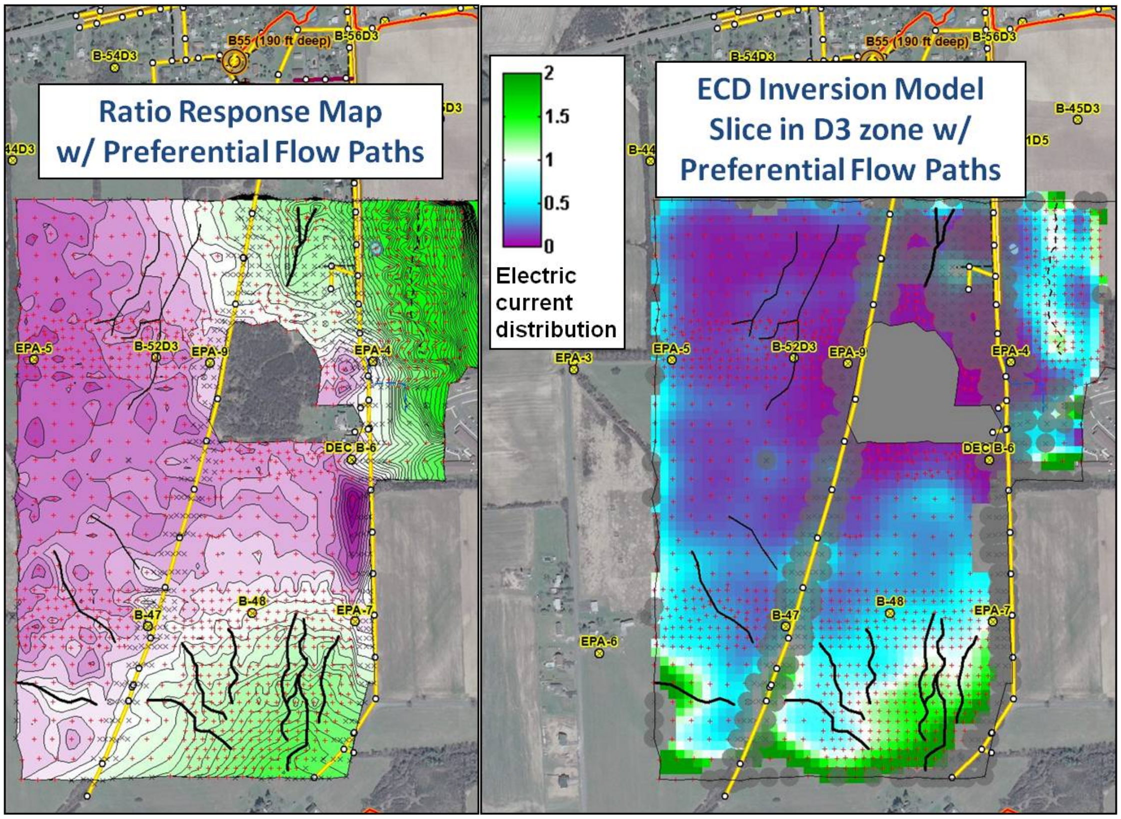

Figure R – Comparison of Magnetic Field Map and Ratio Response Map with Potential Flow Paths

11.5 Possible Flow Paths Below D3 Zone

As mentioned, when an anomalous feature is first observed it can sometimes cause the inversion program to predict the anomaly to extend deeper that it actually is—similar to casting a shadow down through the model. Most of the anomalous features that were first observed in or near the D3 zone continue to increase in intensity going down below the D3 zone. Therefore, electric current distribution below the D3 zone is less predictable. Most of the subtle flow paths, however, are first observed in or very near the D3 zone.

12.0 SUMMARY OF PHASE II INVESTIGATION

12.1 Summary of Results

The primary objective in performing the Phase II AquaTrack geophysical investigation was to identify potential preferential groundwater flow paths in the D3 zone beneath the extended study area. A single electrode configuration was employed to energize the D3 zone in order to determine how electrical current aimed and driven through the targeted subsurface study area would flow and react with the groundwater regime. After removal of near surface interferences, the magnetic field from the energizing perspective suggested that electric current flows in the subsurface in a relatively uniform manner, with some very subtle preference in specific areas.

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The more notable electric current flow paths are noted with solid black lines in the magnetic field and RR maps (see Figure S).

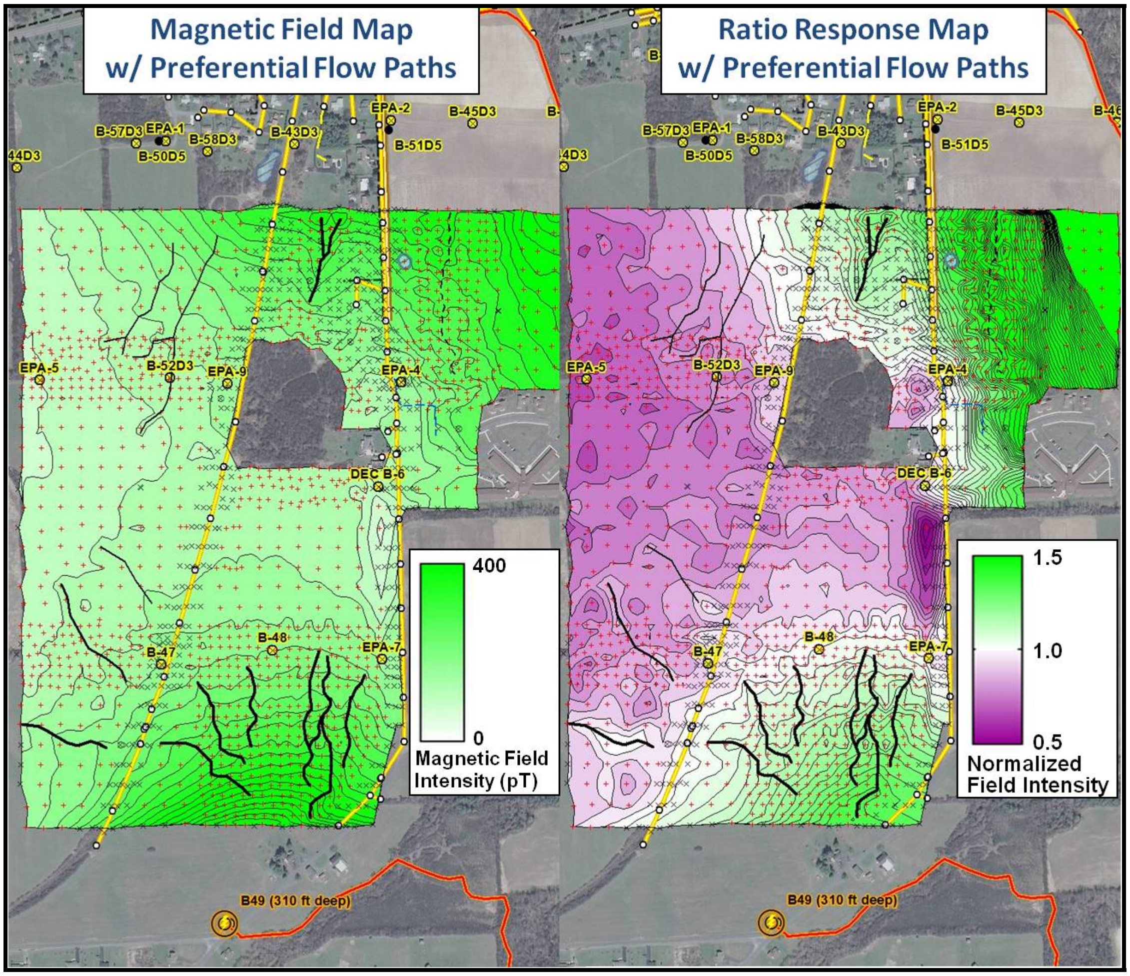

Figure S – Most Notable Flow Paths Observed in Magnetic Field and Ratio Response Maps

In order to determine the vertical location of these subtle flow paths, the RR data was subject to an ECD inversion program. The results of the inversion program indicated that the vertical positions of these subtle flow paths are best observed in or near the D3 zone. The dashed thin black line in the northeast corner of the study area identified a flow path occurring near the surface ground.

12.2 Summary of Investigation

To summarize the results of the Phase II investigation, there are eight important observations and findings that were derived from the reduced and modeled data. These observations and findings are:

1. Because saturated strata normally act as a good subsurface electrical conductor (through earthen materials and native bedrock), and because groundwater found in the D3 zone is

more conductive than groundwater found in the formations located above the D3 zone, the signature electric current used in the AquaTrack survey preferentially follows and concentrates in areas of higher porosity where the ionized groundwater accumulates and/or flows preferentially through the D3 zone. As a result, the AquaTrack methodology has allowed for the characterization of electric current flow beneath the area of investigation.

2. A single survey configuration was used to energize the D3 zone in order to explore how electrical current injected into the subsurface would flow and react with the groundwater regime. The more electrically conductive zones have been interpreted as subtle but potential preferential groundwater flow paths.

3. Magnetic field measurements have been shown to provide clean, consistent, and reliable data based on quality control criteria such as circuit continuity, signal strength, signal-to-noise ratio, measurement repeatability, spheric noise, 60 Hertz signal, etc.

4. As experienced in the Phase I work, conductive culture was problematic at the site. Conductive culture is often a factor because it tends to be near-surface and can cause large anomalies that can hide some of the magnetic field coming from the subsurface as experienced in the survey. Fortunately, the locations of most of the near surface conductive features are known and their influence on the magnetic field was identified and removed from the data set.

5. A homogeneous model was created for the survey configuration and compared to the physical magnetic field map. Similarities between the physical and homogeneous model indicate a more homogeneous environment (fairly uniform electric current flow distribution) in comparison to a heterogeneous environment (where electric current focuses along specific pathways).

6. In order to enhance areas of greater or lesser conductivity through the extended study area, the magnetic field data was divided by the model's predicted magnetic field. As a result, a ratio response map was created. The RR map removes electric current bias from the data set and shows areas of greater or lesser conductivity than that predicted by the model.

7. In order to identify anomalous features that possibly represent preferential groundwater flow paths, anomalous features that showed up along at least three adjacent contour lines and defined by a number of measurement stations were used to identify potential preferential flow paths.

8. Because electric current flows more homogenously then heterogeneously (even more so than in Phase I), it was difficult to model the weak and subtle flow paths. Therefore, the RR data was subjected to an inversion algorithm that predicts the distribution of electric current flow in three-dimensional space. The ECD model suggested that the subtle flow paths identified in the filtered magnetic field and the RR maps were occurring in or near the D3 zone.

13.0 RECOMMENDATIONS

13.1 General

Based on the filtered magnetic field data, predicted magnetic field model, RR map and ECD model, the results of the investigation can be used by the Owner, its consulting engineers and the various regulatory agencies to provide a guided and cost effective approach in helping make informed decisions concerning the placement of additional groundwater monitoring wells in the extended study area.

13.2 Recommended Well Locations

There are no well locations recommended as part of the investigation. Rather, the filtered magnetic field contour map, RR map and ECD model should be used as a guide to determine monitoring well locations that meet the following criteria:

1. Anomalous features that show up on at least three adjacent contour intervals.
2. Anomalous features that are defined by several measurement stations.
3. Anomalous features identified in the ECD model.
4. Where a consensus between private property owners, regulatory agencies and the Owner can agree.

13.3 Other Recommendations

It is recommended that the maps, models, and tables provided in this report be carefully understood and utilized as a planning tool. There are no other recommendations made or implied as a result of this investigation. Willowstick does not specialize in seepage remediation, engineering consulting or construction. Willowstick simply focuses its expertise on groundwater characterization by mapping, modeling and monitoring electric current flow distribution through the subsurface area of interest.

The information contained herein should be compared with known information of the site to further characterize and substantiate subsurface conditions impacting groundwater flow beneath the extended study area in the D3 zone.

14.0 DISCLAIMER

14.1 General

Every AquaTrack investigation is highly unique and considering the vastly different possibilities of cultural interferences, geologic, electrical and hydrologic conditions, the principal challenge of every investigation is to establish electrical current flow through the subsurface that will help define and characterize changes in electrical properties.

In any given survey, it should be recognized that the AquaTrack technology's degree of success is largely dependent upon the ability to establish electrical current flow that will follow and stay focused in the targeted medium. The good news for this project is that the horizontal dipole configuration employed for the investigation allowed sufficient electrical current to concentrate and flow through the D3 zone of interest. Some of the signature electric current strayed to the surface of the ground and flowed along conductive culture. The influence of near surface electric current was removed in order to characterize the electric current flow at depth.

The information gathered through the AquaTrack methodology suggests that the survey configuration and data grid spacing were appropriately applied to the site and that the overall investigation's findings are reliable.

It should be recognized that Willowstick's Controlled Source – Audio Frequency Domain Magnetic (CS-AFDM) geophysical tool (AquaTrack) is a new and emerging technology. The data, interpretations and recommendations obtained from the AquaTrack survey and modeling methodology is based upon sound applied physics and Willowstick's experience in working with and developing the technology. By definition, the evaluation of geologic, hydrogeologic and/or geophysical conditions is a difficult and an inexact science. However, Willowstick feels strongly that the technology has yielded information that can greatly help to characterize potential preferential groundwater flow in the D3 zone beneath the extended study area.

Willowstick certifies that this geophysical investigation and report was conducted and prepared by those listed in Appendix E. Willowstick makes no warranty or representation regarding the acceptability of any findings or recommendations in this report to any governmental or regulatory agencies whatsoever.

APPENDIX A – INTERPRETING MAGNETIC FIELD FOOTPRINT MAPS

The horizontal magnetic field map or "footprint map" helps identify the horizontal position of electrical current distribution across and beneath the study area. In studying the magnetic field contour maps, keep in mind that electric current will follow long conductors or conductive zones that facilitate movement of electrons between paired electrodes.

The shape of the contour lines reveals electric current flow patterns related to conductive pathways. The magnetic field contour interval is 25 pT for the maps created in the report. The sensitivity of the magnetic field receiver (AquaTrack instrument) measures between 5 and 10 pT. Thus, the reason for the 25 pT contour interval. This contour interval is well within the sensitivity of the instrument.

It is generally more important to pay attention to the shape of contour lines rather than the shading that indicates relative magnetic field strength. Although the contour shading helps distinguish between areas of high magnetic field (dark green) and low magnetic field (light green), it can be somewhat misleading if interpreted directly as locations of subsurface electric current flow related to areas of higher porosity in the saturated zones because the magnetic field is affected by the electrical current bias and possible conductive culture for the given circuit wire/electrode setup.

The AquaTrack technology uses ***relative*** magnetic field contour lines to characterize patterns in electric current flow, in contrast to a topographic map which provides values of each contour line related to a benchmark for standardization (i.e., elevation 0 = mean sea level). To achieve standardization for magnetic field strength for the AquaTrack technology would be very difficult due to the highly variable conditions of each survey (i.e., circuit wire/electrode configuration, voltage and amperage requirements, geologic conditions, electrical properties of subsurface formation, etc.). The magnetic field contour lines shown in Figures H, I and J are provided simply for comparison purposes to one another to determine where electrical current flowing in the targeted study area concentrates and gathers. Nothing more should be construed from the magnetic field contour lines.

To the untrained eye, reading a magnetic field contour map could be compared to reading a topographic quadrangle map. On a topographic map, the ridge lines connecting the peaks could be thought of as pathways offering the least resistance to traverse. In the same way, these lines in the magnetic field maps represent paths of least resistance for electrical current to follow, although it undergoes some measure of dispersal and re-concentrating in more complex ways than can be fully described or modeled. By identifying these high points and ridges and connecting them together through the study area, the center position of preferential electric current flow can be identified.

APPENDIX B – MEASUREMENT STATION QUALITY CONTROLS

B.1 Signal Strength and Signal-to-Noise Ratios

Signal strength and signal-to-noise ratios are determined for every measurement station and are monitored to ensure that the AquaTrack signal is at least two times stronger than the average background noise in the spectrum. If the signal-to-noise ratio falls below two, the data is considered unreliable and is removed from the data set. There were no measurement stations removed due to poor signal to noise ratios.

B.2 Criteria to Distinguish Near-Surface Interferences

Stray electric current flowing on near-surface power lines and other utilities was problematic for interpreting electric current flow at depth. It therefore became necessary to remove near surface interference in order to properly interpret the distribution of electric current flow in the subsurface. Near-surface interferences were distinguished by three additional quality control criteria that were applied after the signal-to-noise ratio criteria. Counting the signal-to-noise ratio criteria as the first, a total of four removal criteria were applied:

1) Signal to Noise Ratio (previously explained)
2) Normalized Gradient Filter
3) Distance from Culture
4) Point-Specific Professional Judgment

B.3 Normalized Gradient Filter

An analysis of magnetic field gradients provides a good way to separate signals caused by near-surface conductors from signals that originate at given depths such as the D3 zone. In Figure B1, both shallow (red dot) and deep (green dot) conductors are represented by energized wires running perpendicular to the page through the points shown.

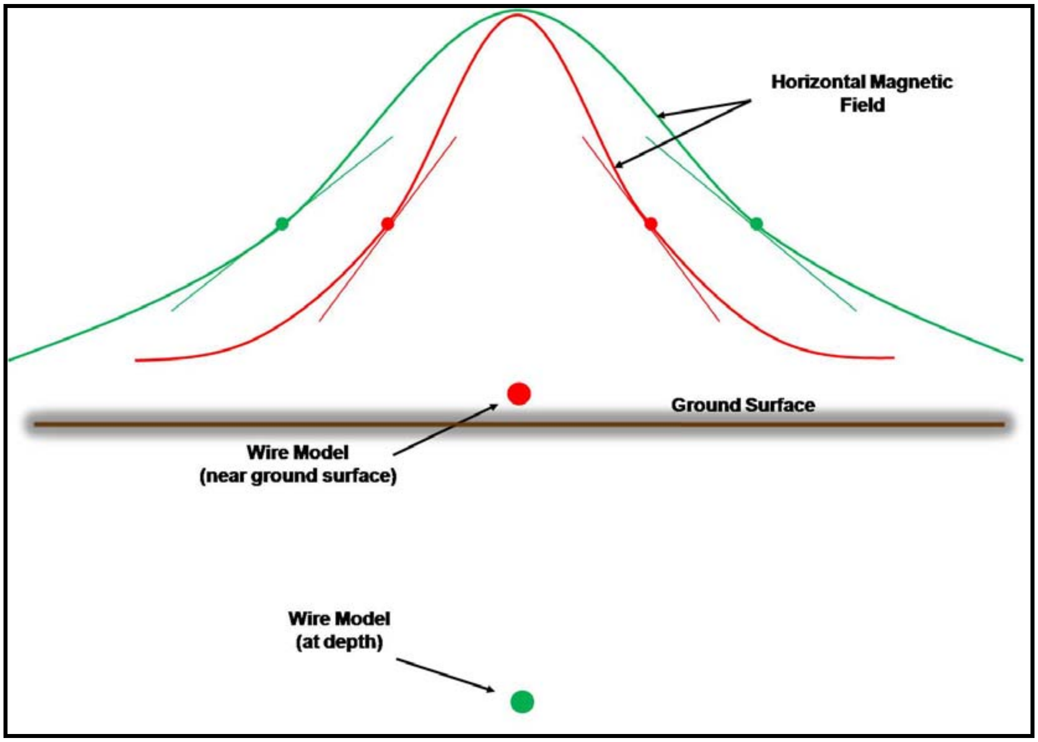

Figure B1 – Normalized Gradient Filter

The red and green curves show the corresponding response curves of the horizontal magnetic field measured at the surface. Figure B1 demonstrates that near-surface conductors (red) cause anomalies having much steeper slopes or gradients than signals originating from depth (green).

Based on theoretical modeling, the maximum normalized gradient that can be produced from a flow path in the D3 zone is 1.41% per meter. For comparison, an electric current flowing on a typical 9-meter high overhead power line can produce a normalized gradient response up to 7.2% per meter.

Although the gradient filter method is very effective, by itself, it does not separate out all cultural influences. Steep gradients can occur over very short distances, and they can sometimes pass detection due to discrete station spacing, especially where the grid is sparse and near survey edges. It is also important to consider that near-surface electric currents may be much weaker than those at depth, but can still influence readings within a very short proximity—sometimes less than the typical station spacing. The influence in such a case may be significant even if it does not cause a measureable high gradient. For this reason, another criterion specifically for the removal of readings near culture is necessary.

B.4 Distance from Conductive Culture

There were a significant number of measurement stations taken at close intervals beneath and on either side of the overhead power lines that cross through the study area. The purpose of taking these measurements was to determine the distance away from the overhead power lines where the magnetic field dropped suddenly. Measurements within 55 feet (16.8 m) of utility lines were found to be influenced by the near surface conductors and were automatically removed from the data set. This was the same distance as observed while performing the Phase I work. The objective of this filter is to remove additional points that cannot be trusted due to the high probability that they are influenced by surface culture. The cutoff is half a station spacing (50 feet) plus an extra 5 feet to account for some variability in the grid. This was chosen because steep gradients can sometimes occur in shorter spaces and potentially be missed by the normalized gradient filter.

B.5 Point-Specific Professional Judgment

The gradient filter and distance to culture criteria remove the majority of measurement stations affected by near surface conductive culture. Nevertheless, there still remains a "gray zone", where some data that slips past these two criteria should be considered by subjecting it to point-specific professional judgment. Removal of measurement stations using professional judgment usually takes place only when the above criterion breaks down due to survey edges or gaps in the data as mentioned. In any event, professional judgment is used as the final criteria to determine the quality of all measurement stations.

B.6 Measurement Stations Removed from Data Sets

Table B.1 presents the total number of measurement stations recorded for the survey and the number of stations removed based on each quality control criterion. Some were removed for more than one reason. . Stations that passed the quality control measures are shown with red crosses ("+" signs) in the figures. No measurement station was removed as a result of a poor signal-to-noise (criteria #1). Stations removed after criterion #2 and #3 were applied (normalized gradient filter and distance-from-culture cutoff) are shown in the figures with an "x". Stations removed by professional judgment (criteria #4) are shown in the figures with a circle around the "x". A very small percentage of the measurement stations were removed through the point-specific professional judgment criterion.

Survey #	Total Measurement Stations	Criteria #1: Low Signal-to-Noise	Criteria #2: Gradient Filter	Criteria #3: Distance from Culture	Criteria #4: Professional Judgment	% of Points Kept
Phase II	1,746	0	420	92	6	70

Table B.1 – Points Removed by Quality Control Measures

APPENDIX C – PHASE I AND PHASE II COMPARISON

C.1 Summary of Phase I Investigation

The resultant magnetic field information obtained from the Phase I investigation revealed a high degree of homogeneity of electric current flow through the 3D zone with some areas of subtle preferential flow. Unlike the Phase II investigation, the Phase I investigation employed three survey perspectives. The Phase II employed only a single energizing perspective. In some cases, more than one energizing perspective is helpful to identify and confirm the more dominant flow of electric current through a particular study area. It is sometimes difficult to know just how many or which electrode configuration will enable adequate characterization of the subsurface flow patterns. In some cases, only one electrode configuration is required to obtain sufficient information about a particular site; whereas, in other cases, several configurations may be required (depending upon cultural influences and the complexity of the site). Determining the number of energizing perspectives and which one(s) are best suited for a particular site often requires trial and work. Regardless, only one energizing perspective was used in the Phase II work.

In the Phase I investigation, preferential flow paths were identified and substantiated by data from three different survey configurations. An electric current flow (EFC) model was created to provide the best representation of probable groundwater flow paths (see Figure C1).

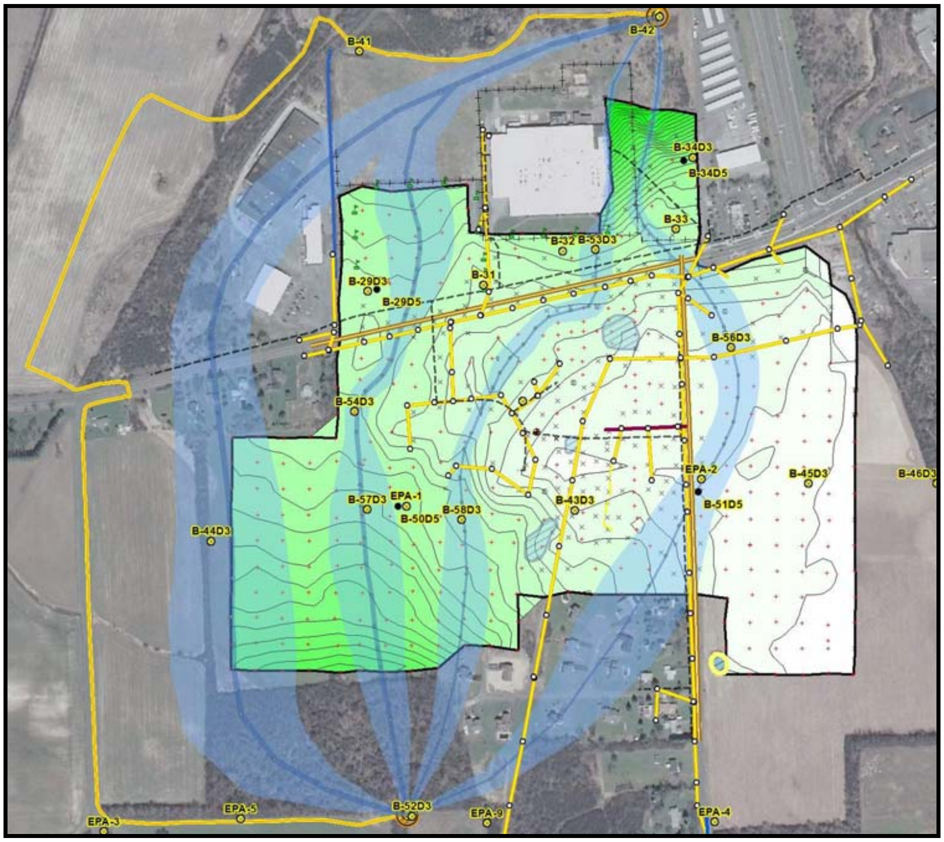

Figure C1 – Phase I Magnetic Field Contour Map w/ ECF Model

There were three areas that were interpreted as potential preferential groundwater flow paths crossing beneath the study area in the D3 zone. A fourth potential flow path was identified by the ECF model and was shown on the figure outside the study area to the west. This part of the ECF model was based on conjecture, and was drawn for visual purposes suggesting that a significant amount of electric current flowed around the study area to the west.

C.2 Comparison of Phase I and Phase II Models

Figure C2 presents a side-by-side comparison of the Phase I and Phase II models.

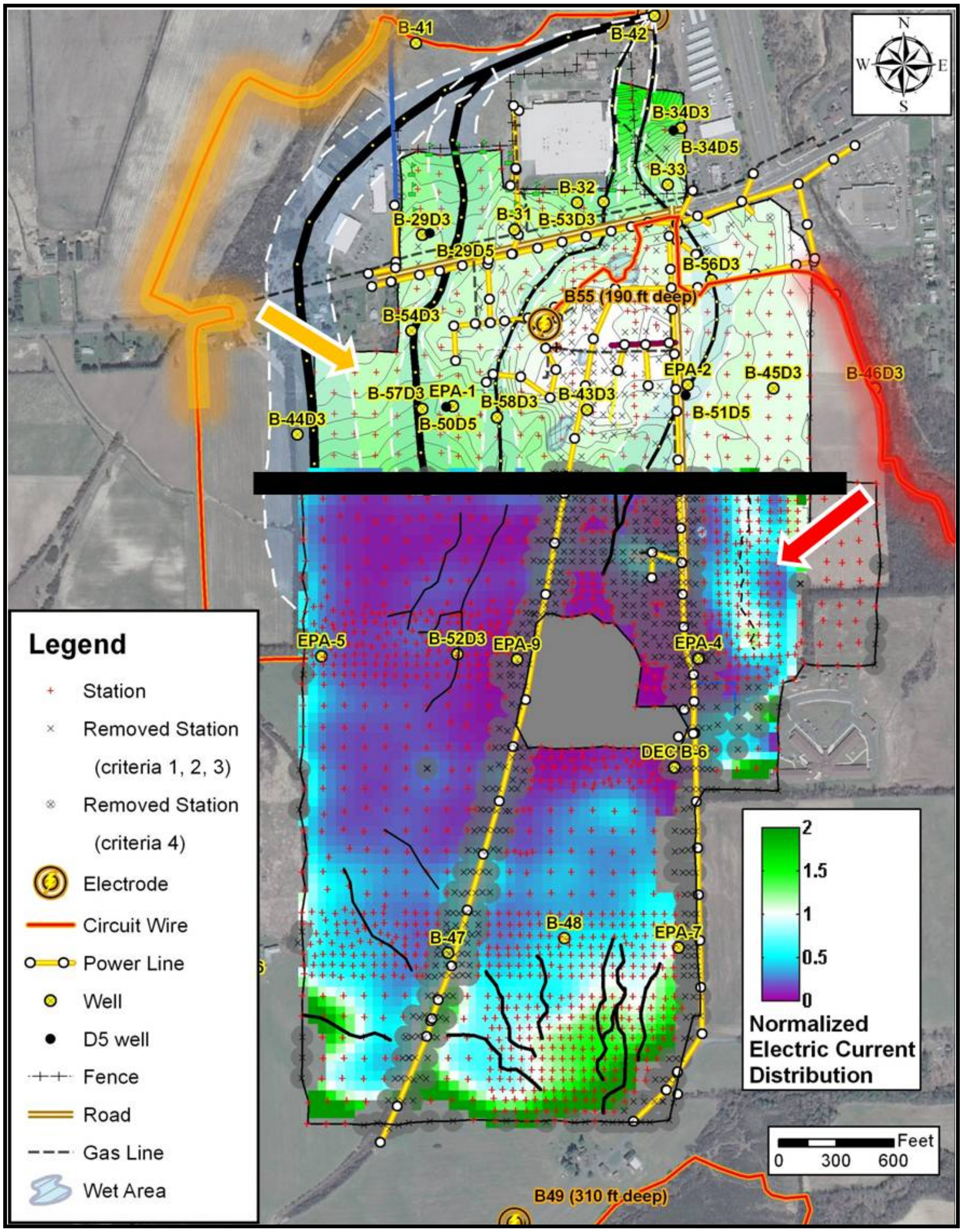

Figure C2 – Comparison of Phase I and II Models

Care should be taken when comparing the two models, which use completely different energizing perspectives and modeling techniques. There are, however, similarities between the two data sets. For example, the two most eastern flow paths identified in the Phase I work have common anomalous features in the Phase II model.

The shallow flow path observed in the northeast corner of the Phase II data is also present in the Phase I work. During the Phase I work, this flow path was observed to be very subtle and weak and thought to be a near surface anomaly. The Phase II work appears to support this interpretation.

The orange arrow in the upper left hand corner of the figure identifies secondary magnetic field effects as a result of the location of the circuit wire in the Phase I investigation. The red arrow on the right side of the figure represents secondary magnetic field effects as a result of the location of the circuit wire in the Phase II investigation.

APPENDIX D – WHITE PAPER (AQUATRACK TECHNOLOGY EXPLAINED)

Table of Contents

1. AquaTrack® Methodology

AquaTrack is a geophysical technique that uses Controlled Source – Audio Frequency Domain Magnetics (CS-AFDM), which uses a low voltage, low current audio frequency electrical signal to energize the groundwater or seepage area of interest. The diversity of site conditions often necessitates wide variations of electrode and antenna configurations and interpretive parameters. Electrodes are usually placed upstream and downstream of an earthen embankment. The upstream electrode is placed in the reservoir water body distal from the face of the embankment. The downstream electrode is placed in strategic locations (seeps, observation wells, or other downstream locations) to facilitate contact with seepage flowing through the embankment. Following the preferential pathways of least resistance, the electrical current concentrates in highly saturated zones through, beneath, and/or around the earthen embankment. As the electrical current takes various paths through the area of investigation, it creates a magnetic field characteristic of the flowing electrical current. This unique magnetic field is identified and surveyed from the surface of the ground using sensitive magnetic sensors.

The horizontal and vertical magnetic field magnitudes are measured and recorded to define the electrical current's distribution and flow patterns beneath the subsurface. In nearly all cases, the paths of least resistance for the electrical current to flow in are the seepage paths through the embankment. The locations of measurement stations are obtained using a Global Positioning System (GPS) unit and are recorded in a data logger along with the magnetic field data. The measured magnetic data are then processed, contoured, modeled and interpreted in conjunction with existing hydrogeologic information, resulting in enhanced definition of the extent of subsurface water saturation in the study area. This is done in an effort to monitor, identify, and model seepage pathways for the client to facilitate remediation before it reaches unacceptable proportions.

It should be noted that although the AquaTrack technology can quickly and accurately identify groundwater concentrations and probable flow paths, it does not identify the amount of water or the direction of groundwater flow along a particular pathway. The quantity of water and the direction of groundwater flow should be determined by other field methods such as pump tests, water bearing formation characteristics, regional groundwater flow, topographic slope, or potentiometric head differences, etc.

2. Survey Layout and Energizing Configuration

In most cases, a horizontal dipole electrode configuration is employed to energize an earthen embankment's study area for the purpose of conducting the AquaTrack investigation. A single horizontal dipole configuration can be used on a small embankment (<1,000 feet in length); however, multiple horizontal dipole configurations are often used on longer embankments and levees (>1,000 feet in length). A horizontal dipole survey entails placing an injection electrode in the water body upstream of the embankment, and placing a return electrode in a seep, monitoring well, or other downstream waters (see Figure 1 below).

In some surveys, a vertical dipole electrode configuration is better suited to investigate a site. In such cases an electrode is placed at or near the surface while the second electrode is placed at depth in a well. This type of setup can be utilized to force the electric signal deeper which can reduce interference from surface culture like metal pipes.

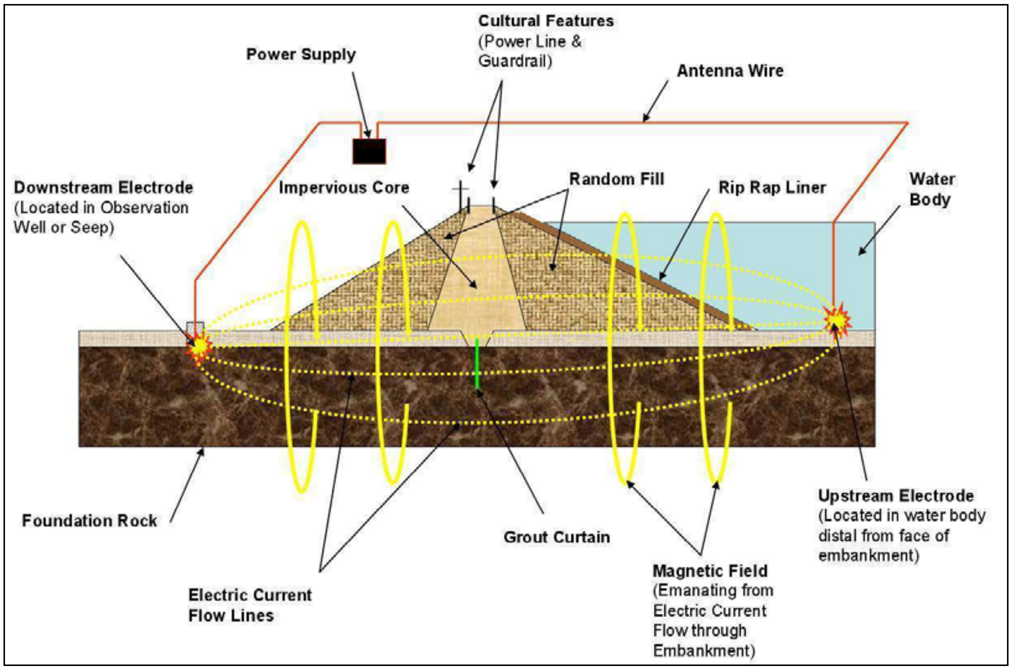

Figure 1 - Typical Horizontal Dipole (Cross Sectional View)

Most investigations differ only in the placement of the return electrode below the embankment which is optimally placed in contact with the groundwater of interest. Electrodes can be set several thousands of feet apart (horizontal separation between upstream and down-stream electrodes). In the case of vertical dipole surveys, the separation can be as far as the deepest available wells in the area will allow. Most earthen embankments and their subsurface foundations are normally within a few hundred feet of the surface—well within the range of the AquaTrack technology utilizing a horizontal dipole at the surface.

To minimize interference from the energizing antenna, the wire connecting the strategically paired electrodes is positioned in a large loop to circumvent the area of investigation, as shown in Figure 2.

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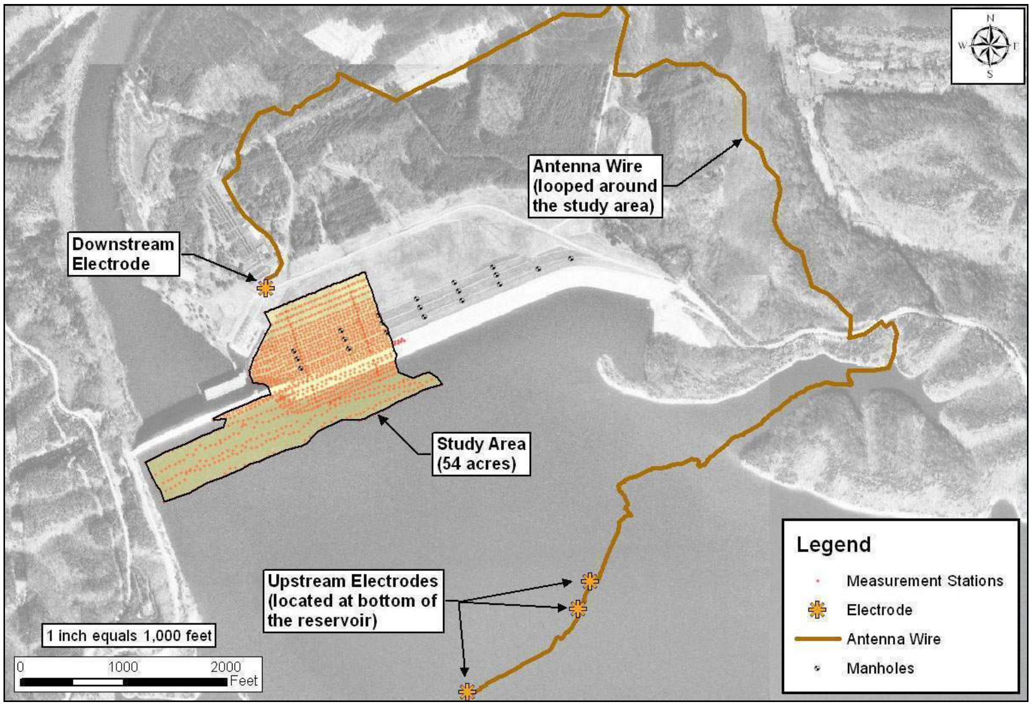


Figure 2 - Typical Horizontal Dipole (Plan View)

Because the electric current is highly concentrated in the antenna wire and all around the electrodes, it is important that these parts of the circuit be located outside the study area far enough to minimize interference. A strong magnetic field is created by the highly concentrated electric current and, generally, very little discernable subsurface information can be obtained near the energizing equipment because the magnetic signal dominates the earth-response signal. A physical example of this effect would be like looking at the sun. The sun is too bright and domineering to see any distinguishable features immediately around it. However, as one looks away from the sun, things become very clear and distinguishable. This is the concept behind the antenna-electrode placement. The antenna-electrode configurations are designed to allow the greatest amount of electric current to flow through the study area of interest to highlight its features while at the same time minimizing the interference from the electrical current flowing in and out of the electrodes and along the antenna wire.

An AC electrical current, with a specific signature frequency (380 or 400 Hertz) is applied to the paired electrodes. The overall approach to the fieldwork includes injecting and driving an electrical current between the paired electrodes located on either side of the embankment to determine where electrical current flows and concentrates in the subsurface. As the electrical current follows preferential flow paths in the study area between the electrodes, it generates a recognizable magnetic field that is measured over the crest of the embankment and on the down-stream and up-stream faces of the embankment, and in some cases over the water body itself in front of the embankment. Magnetic field measurements are taken on lines that typically range from 5 to 15 meters apart with measurements on each line spaced at 5 to 15-meter intervals. These distances vary from one project to another depending upon required survey resolution and site conditions including terrain and vegetative growth. The measurement pattern or grid setup used for a typical investigation is normally approved by the owner to provide sufficient detail and resolution to adequately delineate seepage while at the same time optimizing funds available for the investigation.

The X, Y, and Z coordinates of each measurement station are recorded as part of the field work. The stations are designated by small red crosses or "+" signs shown in the figures. These spatial locations are critical to data processing, comparison of surveys, modeling and interpretation.

3. Equipment

The equipment used to measure the magnetic field induced by electrical current flowing in the groundwater of interest includes: three magnetic sensors oriented in orthogonal directions (X, Y, and Z axes); a Campbell Scientific CR1000 data logger used to collect, filter and process the sensor data; a Global Positioning System (GPS) used to spatially define the field locations; and, a Windows-based Allegro CX handheld computer used to couple the GPS with the magnetic field data and store it for subsequent reduction and interpretation. All of this equipment is mounted on a surveyor's pole and hand carried to each field station (see Figure 3 below).

Figure 3 – Willowstick Instrument

The magnetic receiver (nicknamed the "Willowstick") filters and monitors various frequencies, amplifies the signals through noise-reduction algorithms, measures the strength of the signature magnetic field, and converts all the information into recordable data that is ready for subsequent processing and corrections, collectively called data reduction. The data reduction process includes a number of corrections and normalizations to account for: (1) differences between instruments used in the investigation; (2) atmospheric noise (diurnal magnetic variations, magnetosphere activity, etc.); (3) effects induced by the electrodes and antenna wire; and (4) ground noises (60 hertz power and other manmade sources).

4. Physical Principles Involved in AquaTrack

The AquaTrack technology uses well-known electromagnetic (EM) principles and concepts but differs with other technologies in its execution of the application of these principles to identify, map and model groundwater distribution patterns through earthen embankments. The combination and interplay of tracer concepts with several electrical phenomena and adaptation of several electromagnetic principles are used to prove the interpretive foundation on which the AquaTrack technology is founded. The following is an overview of these principles and how they are used to identify, map and model subsurface flow distribution patters through earthen embankments.

- Electricity, like all physical systems, follows the path of least resistance. Groundwater is generally the best subsurface electrical conductor.

- Electrical current flowing in a conductor generates a magnetic field with characteristics that reflect the location of its source.

- Based on Maxwell's equations, an alternating electrical current in a conductor will generate an alternating magnetic field around the conductor. The converse is also true. An alternating magnetic field will generate an alternating electrical current in a conductor that is under the influence of the alternating magnetic field.

- Two coils in close proximity to each other can be coupled magnetically. A transformer is a special case of two magnetically coupled coils. The electric current in the primary coil creates a magnetic field which then induces an electric current in the secondary coil completing the magnetic coupling. The primary coil in the AquaTrack technology is created by a large primary loop that consists of the antenna wire, electrodes, and the preferential conductive pathways (groundwater) in the subsurface between the electrodes. The AquaTrack technology's secondary coils are in the magnetic receiver. When the magnetic receiver is under the influence of the magnetic field emanating from the primary coil (conductive subsurface flow path), the three receiver coils sense and measure the strength of the magnetic field emanating from the primary coil.

- Conductive features will gather electrical current flowing in the ground. This is referred to as current gathering. Electric current flowing in the ground will follow long conductors or conductive zones that facilitate movement between point A and point B (in our case, the two electrodes). There are four general classes of long conductors in the ground:

1. The first class of conductors is subsurface groundwater flow paths and channels. When electric current is biased to flow through an earthen embankment, the electrical current will want to concentrate and flow in the most conductive medium, which is the groundwater.

2. The second class of conductors is manmade. These include: communication cables, overhead and underground power lines, underground metallic pipelines, metal fences (chain link, barb wire, etc.), railroad tracks, steel guardrails, and other elongated continuous conductors. The locations of such are usually known, thus they can be accounted for when interpreting the data. Note that short conductors such as barrels, landfill refuse, and isolated pieces of metal do not affect AquaTrack.

3. The third class of conductors is mineral deposits such as ore bodies. Because of the nature and distribution of conductive minerals in ore bodies, these are more appropriately classed as semi-conductors, and they are generally easy to distinguish from other types of conductive media.

4. Clay layers and lenses in soils are conductive when energizing with a DC electric signal. This signal will create a charge—referred to as *induced polarization*—on the structure of the clay particles, and it occurs when the positive and negative poles of clay particles align in such a way as to store electric charge. However, when an AC electric signal is applied that continually changes directions back and forth in a pulsing motion, the charges on the clay particles cannot align themselves rapidly enough to permit conduction of the AC signal. This effect is more commonly referred to as electrical impedance or AC resistivity. This forces the signal to follow less resistive pathways than the clay body. Normally, these alternative pathways are found along highly saturated zones through and/or around the clay body where ions are freer to move and conduct the alternating current.[1]

5. Quality Control Measures

There are basically four criteria used to determine the quality of the magnetic field data measured and recorded from the AquaTrack equipment. These are as follows:

1. Circuit continuity between electrodes
2. Signal strength
3. Signal-to-noise ratios
4. Signal repeatability

<u>Circuit Continuity</u>
The magnetic field is measured to characterize how and where groundwater concentrates and flows through the earthen embankment. This field is created from a large electric circuit consisting of the antenna wire, electrodes, and the subsurface located between the strategically

[1] Wait, J. R. *Overvoltage Research and Geophysical Applications* International Series of Monographs on Earth Science. Pergamon Press: 1959.

placed electrodes. An AC signal, typically around 1 amp and 100-150 VAC, with a specific signature frequency (380 or 400 hertz), is applied to the paired electrodes. It is critical that the circuit be established through the subsurface area of investigation in order to map groundwater, and various measurements are taken to ensure this is the case. Every investigation is unique and requires different amounts of energy to create the necessary electric circuit with the groundwater.

Signal Strength

The AquaTrack instrument measures the magnetic field created by the signature electrical current flowing through the area of investigation. The magnetic field strength is measured across three highly sensitive, orthogonally-oriented sensors at each measurement station. The instrument takes a minimum of sixteen sets of 512 magnetic field samples, or about 8000 samples, per sensor at every station. A Fast Fourier Transform (FFT) algorithm is used to determine the frequency spectrum and isolate the AquaTrack signal. Readings are repeated and statistically analyzed until the measurement is derived within an acceptable deviation. The process takes anywhere from 2 to 4 minutes per station to measure and calculate a repeatable and acceptable value of the magnetic field strength. Magnetic field readings are recorded for frequencies ranging from 30 hertz to 720 hertz with a particular focus around 400 hertz (e.g., 30, 60, 90, . . . 360, 370, 380, 390, **400**, 410, 420, 430, 440, 450, 480, 510, 540 . . . 720). Figure 4 below shows an example of frequency spectrum plot where the 400 hertz signal (red bar) is noted to be several times stronger than any other signal within the frequency spectrum.

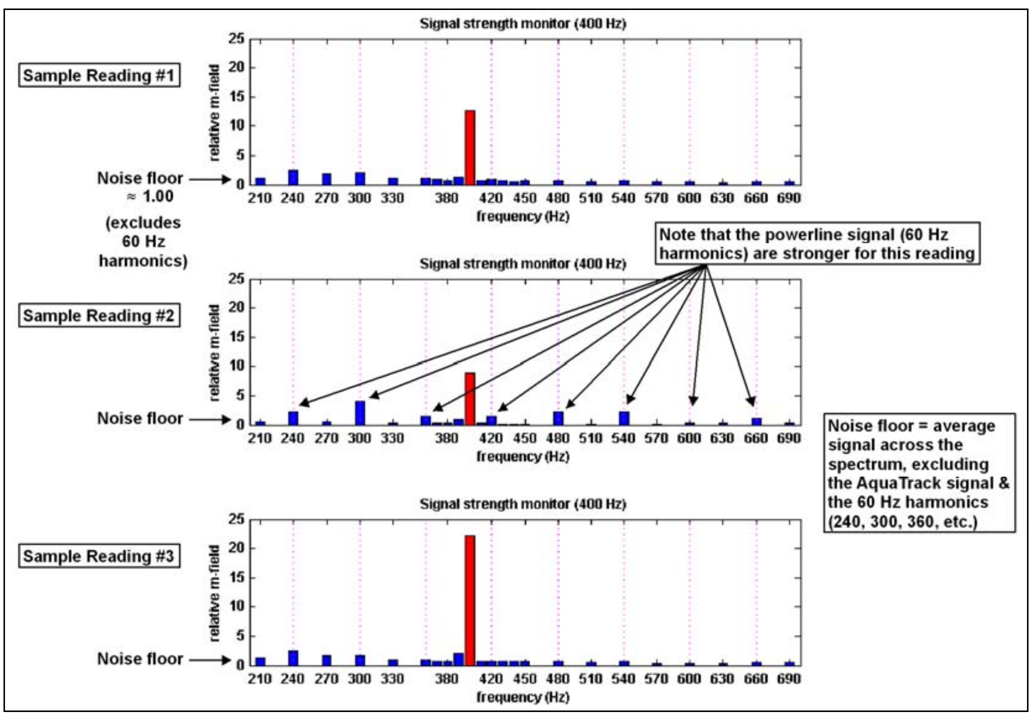


Figure 4 – Sample Readings from AquaTrack Frequency Spectrum

Signal-to-Noise Ratio

The signal-to-noise is computed for each measurement station as the ratio of the 400-Hertz signal to the mean ambient field noise, which is determined from a sampling of several other frequencies in the spectrum. The signal to noise value is contoured and shown over each survey area in an investigation to indicate the degree of reliability of the data (see Figure 5 below).

Figure 5 – Signal to Noise Map

Signal-to-noise ratios are determined for every measurement recorded in the investigation and are monitored to insure that the signal is of sufficient strength to be at least twice as strong as any background noise. If the signal-to-noise ratio falls below 2, the data is considered unreliable. A low signal-to-noise ratio in a particular area is indicative of possibly four things:

1. The electrical current injected into the ground cannot reach the area of low signal-to-noise because the antenna-electrode configuration is not aptly positioned to facilitate electrical current to flow through the area of interest.

2. There is no substantial pathway or conductive zone between the current source and the area showing a low signal to noise ratio. In other words, there is a resistive barrier between the source current and the area in question.

3. There is no conductive media in the particular area in which the electrical current can concentrate or follow; or

4. The electric current flow is highly dispersed throughout the study area and not concentrating in any one particular area or pathway which can result in very low anomalous magnetic field and low signal-to-noise ratios.

Considering the vastly different possibilities of cultural interferences, geologic, electrical and hydrologic conditions, every project is highly unique and the principal challenge of every

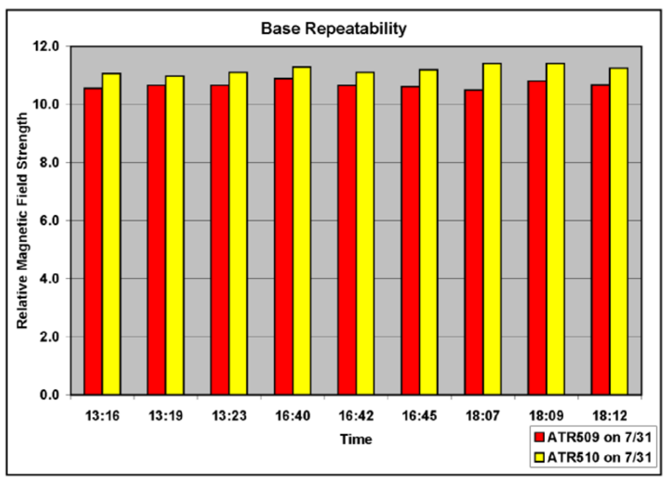
AquaTrack survey is to establish electric current flow that will follow and stay focused in the targeted areas. The degree of success is largely dependent upon this factor—whether or not the electric current follows the saturated medium that it is intended to follow, based upon its electrical properties. Signal-to-noise maps are prepared for every AquaTrack investigation to show that the signal strengths as well as electric current distribution through the areas of investigation are acceptable. If certain signal strength and signal-to-noise criteria are not met, then it can generally be inferred either that there are no preferential flow paths through the study area or a different antenna-electrode configuration needs to be employed to better bias electric current flow through the area of investigation.

Signal Repeatability

As previously stated, the AquaTrack instrument takes numerous readings at each station. Measurement repeatability is determined from base station readings and other repeated field measurements taken throughout the course of the fieldwork. Base stations are established in the survey and are measured and recorded several times per day (morning, mid-day and evening) by each instrument. Repeat stations are read at the start and end of each new survey line. In many cases, additional data are required after reduction and interpretation of the initial data sets to clarify and answer any questions that arise from the initial data. In a typical investigation, repeat measurements normally fall within acceptable deviation (less than 5% from the mean). Examples of repeat base station readings for a typical survey are shown in Figure 6. Note that the calculated deviation for this particular set of data is less than 2%.

Magnetic Field Base Readings

Date	Receiver ID	Aquatrack Signal
07/31/07	ATR509	10.559
07/31/07	ATR509	10.666
07/31/07	ATR509	10.664
07/31/07	ATR509	10.890
07/31/07	ATR509	10.656
07/31/07	ATR509	10.617
07/31/07	ATR509	10.498
07/31/07	ATR509	10.809
07/31/07	ATR509	10.677
07/31/07	ATR510	11.063
07/31/07	ATR510	10.981
07/31/07	ATR510	11.111
07/31/07	ATR510	11.297
07/31/07	ATR510	11.107
07/31/07	ATR510	11.194
07/31/07	ATR510	11.414
07/31/07	ATR510	11.411
07/31/07	ATR510	11.258



The average measurement repeatability is within 2% for the two instruments. Differences between instruments were adjusted as part of the normalization and data reduction process.

Figure 6 – Typical Signal Repeatability

6. Data Reduction

The analysis of the AquaTrack data entails reduction of magnetic field measurements to processed and corrected data sets ready for modeling and interpretation. The data sets are subject to a number of comparisons and corrections to account for: (1) differences between instruments used in the investigation; (2) atmospheric noise including diurnal magnetic variations, ionosphere activity, etc.; (3) effects induced by the electrodes and current bias; (4) antenna effects; and (5) ground noises or manmade interferences (60 hertz power, long continuous conductors including power lines, pipelines, steel guardrails, railroad tracks, etc.).

Correction for differences between Instruments

After assembly, each AquaTrack receiver instrument is carefully tested and calibrated before it goes into the field. Sensors are matched and calibrated to measure within 0.5% error or 1 part in 200 of each other. Subsequent use and wear during the life of the instrument, the shipping and handling, as well as numerous changes in its environment including temperature and humidity, may cause it to drift away slightly from its original calibration. Because of this, the difference between instruments used on any particular project tends to vary somewhat more than the 0.5% calibration error. Typically, instruments will measure somewhere between 1 and 5% deviation on any given project. Figures 6 and 7 show the deviation between instrument readings on some typical projects.

To account for instrument differences, each instrument takes readings at one or more selected base stations numerous times each day throughout the course of the survey. These are measured at the same time and location for each instrument. The mean of each instrument's base readings is compared to the total mean of all base readings, allowing for slight adjustments to be made that effectively normalizes the instruments. This correction is applied to every measurement in the survey and results in a data set that appears to have been collected with a single instrument.

Correction for Diurnal Magnetic Variations

Ambient magnetic field noise can occur as a result of both random and periodic atmospheric activity. The AquaTrack instrument can monitor these changes on many frequencies in addition to the AquaTrack signal. The random influences may come from solar activity that impacts the earth's magnetosphere, or from natural telluric currents in the earth related to thunderstorms or other atmospheric activity. Collectively, these are termed "spheric" noises. These noises are not very predictable, but fortunately they can be monitored. Most of the time, their effect on the AquaTrack signal is very small or negligible.

Diurnal or periodic changes occur in the ionosphere which can influence magnetic field readings. These usually occur at a slow rate and may cause a slow drift in the readings throughout the course of a day. For this reason, the correction for these effects is often called the Drift Correction, and it is accomplished by monitoring the AquaTrack signal at base stations throughout each day for signs of drift. These influences on the data are usually small. Figure 7 shows an example of base station readings that have drifted slightly during a particular day, as shown by the dotted black line.

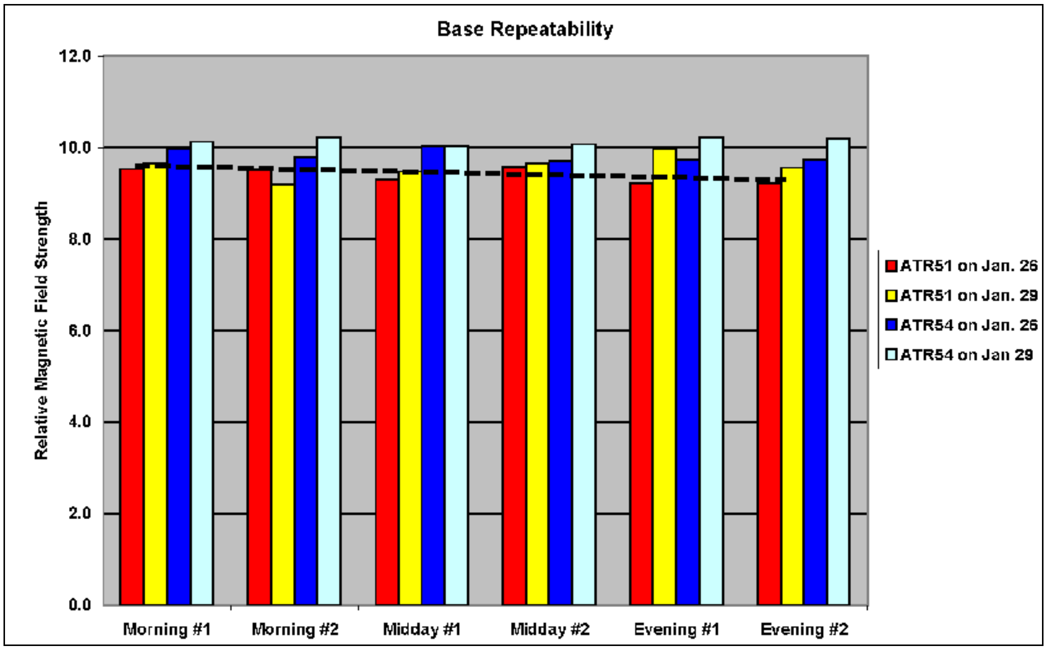


Figure 7 – Typical Diurnal Drift Experienced During Survey

Correction for Electrode Effects

As previously described, electrodes are typically placed in strategic locations upstream and down-stream of the earthen embankment and utilized to bias electric current flow through the study area. The electrodes are located outside the study area as much as possible because all the electrical current is concentrating into and out-of these energizing points. Near the electrodes, the magnetic field is extremely strong ("bright sun" effect) which makes it difficult to identify subsurface flow paths near the electrodes.

Figure 8 below shows an example of a theoretical magnetic field for a homogeneous environment created by simulating electrical current flow through a typical antenna-electrode setup having electrodes on either side of the embankment.

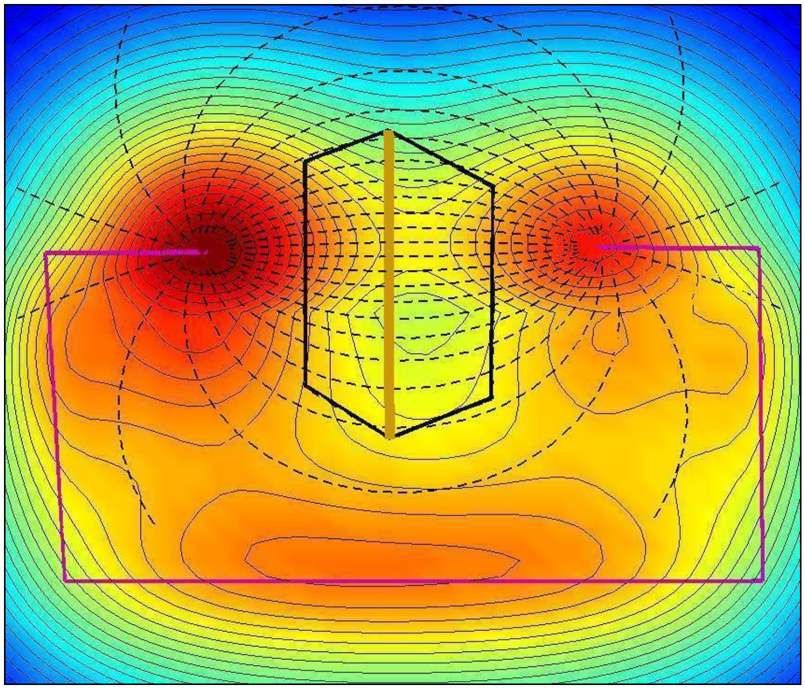


Figure 8 – Electric Current Flow and Theoretical Magnetic Field Model

In this example the "bright sun" on the left (darker red) represents the electrode in a seep downstream of the embankment. The bright red spot on the right represents an electrode in a water body in front of the embankment. The earthen embankment is located between the two electrodes. The two electrodes are placed at different depths. The left electrode is placed near the surface of ground (in a seep). The right electrode is located in the bottom of the reservoir (at depth). Because the left electrode (seep) is closer to the surface of the ground than the right electrode (bottom of reservoir), the "sun-spot" intensity is slightly greater.

The dotted lines represent an approximate "flow-net" of electric current between the two electrodes, which helps visualize how the current would spread out and flow in a homogeneous medium between the two electrodes. In other words, they indicate the preferential direction of the electric current flow in a homogeneous case. This model, however, is missing the most critical part of the electrical circuit, which are the conductive groundwater flow paths between the electrodes. Understanding the magnetic field response from the electrodes and the antenna enables the effective removal or reduction of the "sun-spots" and similar effects from the antenna, which results in a clearer magnetic field footprint of the conductive groundwater flow paths.

Electrode corrections are made by removing empirically-derived "decay" functions from the data. These decay functions describe the magnetic field effect as a function of distance from the electrode. An example is shown in Figure 9, where the yellow line represents the decay or fall-off rate of the magnetic field strength as one moves away from the electrode. Each magnetic field measurement is plotted (blue dots) in relation to its distance from the electrode.

Once the correction is made, preferential flow paths in the "footprint" map generally become much more pronounced. The most important quality control measure in performing this correction is that the defined preferential flow paths *must* also be evident in the raw data to be considered valid. The goal of the correction is to enhance or "bring out" these flow paths by making them easier to see in the footprint map.

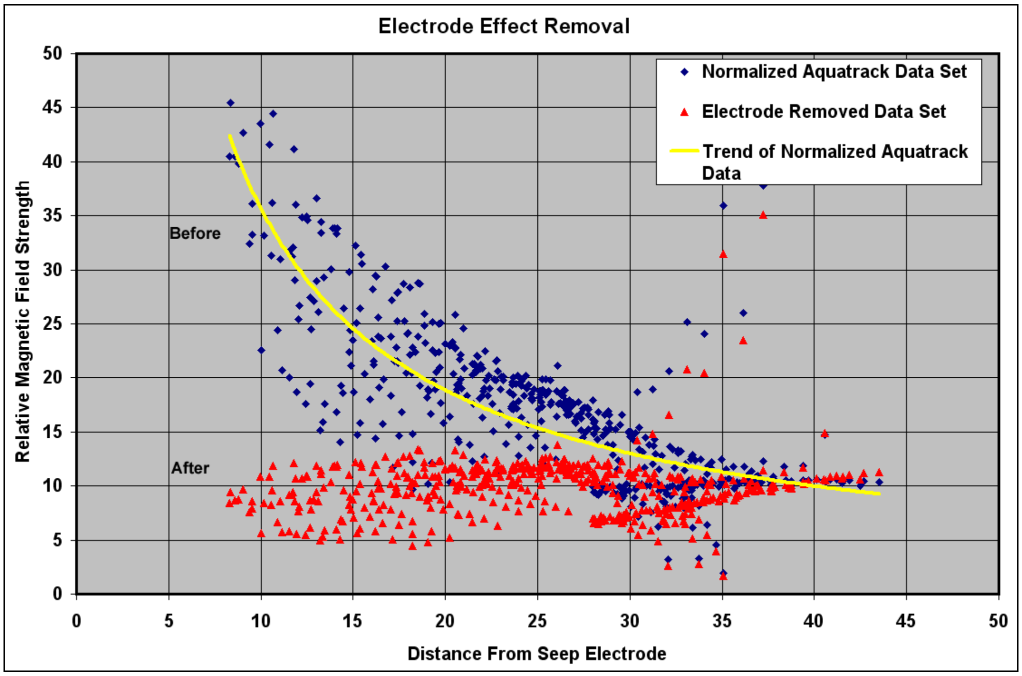


Figure 9 – Profile View of Corrected Electrode Effects

Figure 10 visually portrays how the electrode effects are removed from the data by showing the magnetic field strength represented in a 3D topography-like view. The side-by-side comparison of the data "before" and "after" the correction helps to visually understand the influence that electrodes have on survey data. Note how the "peak" or "sun-spot" effect show up clearly in the "Before" data due to the proximity of the seep electrode on the downstream side. The "After" correction view shows the data with the electrode effects clearly removed. Note that the upstream reservoir electrode in this case is too far away to have any noticeable impact on the data.

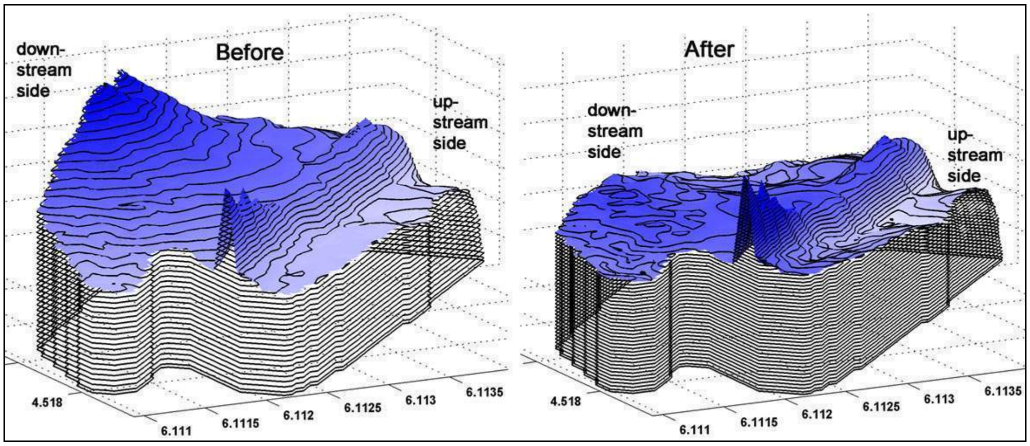


Figure 10 – 3D View of Corrected Electrode Effects

Correction for Antenna and Regional Effects

As previously mentioned, an antenna wire is necessary to connect the injection and return electrodes together to complete the transmitter circuit. All electric current used to energize the ground is conducted through the antenna wire; therefore, it has the potential to influence the magnetic field readings. Fortunately, the antenna usually has lesser influence than the electrodes in most surveys. This is due to a number of reasons. First, the antenna can be routed out and away from the area of investigation. Second, the current flow vector in the antenna wire running along the ground produces a predominantly vertical magnetic field component at most of the field measurement locations, while the subsurface flow paths can be distinguished by their predominantly horizontal component signal.

Like the electrode effect, the antenna influence depends very much on the distance from the survey stations. However, it also depends on other geometrical factors. Fortunately, the antenna influence is very predictable because the location of the antenna wire is always mapped with the GPS equipment. The correction process is in many ways similar to the removal of the electrode effects. Generally, the distance from the measurement station to the antenna is much greater than to the electrode, and the decay often appears almost linear in the area of investigation. Again, the general idea is to predict the antenna influence and remove it from the data set, ultimately enhancing the presence of the subsurface conductive zones.

As depicted in the homogeneous model, the electrodes and the antenna wire create predictable magnetic fields because their locations are known and the amount of electrical current flowing along the antenna wire and the electrodes is known. Mathematical corrections are applied equally to all measured data by subtracting functions that predict the influence of the electrodes and the antenna. The algorithms developed for the AquaTrack data reduction process are considered trade secrets. The mathematical corrections are based on Maxwell's equations and on empirical relationships and formulas developed by Jerry Montgomery, Ph.D. and Rondo Jeffery, Ph.D. of Willowstick Technologies. The corrections are not always perfect and sometimes produce better results in certain portions of a survey than in others—the adjustments are like focusing a camera lens. The goal is to produce a "footprint" map with the unwanted effects significantly subdued so that a picture of subsurface flow emerges.

Manmade Interferences
Once the field data has been reduced and normalized (corrected), manmade interferences must then be accounted for. It is preferred that all manmade interferences are known prior to a survey investigation. If unknown, these interferences can often be recognized by their specific signature signals in the data, especially by analyzing the vertical field data in conjunction with the horizontal data. Once recognized, these features can be accounted for, corrected, and/or removed from the final reduced data set. Some of these interferences include:

1. Ground noise from 60 Hz signal (from nearby electrical generating equipment, overhead or buried power lines, any subsurface cathodic protection of pipes, etc.)
2. Cultural features (buried pipes, steel cased wells, steel guardrails, etc.)

These various features are specific to an individual site; and as stated, they need to be identified, reported and portrayed if at all possible. In some cases, long linear conductors like pipes or guardrails can be modeled and removed with methods similar to that used for the antenna wire; however, because these features are usually very near to the surface, the geometric locations must be very accurately defined in order to perform an accurate correction. For this reason, such cultural features must instead be dealt with by other means—such as removing the data points that are strongly affected by them or by leaving the cultural anomaly in the data and just making note of it on the footprint map so that it is not mistaken for a subsurface flow path.

7. Application of Physical Principles Involved in Modeling

To understand the application of the physical principles used in modeling the AquaTrack data, consider what happens when electrical current flows along a wire (see Figure 11 below).

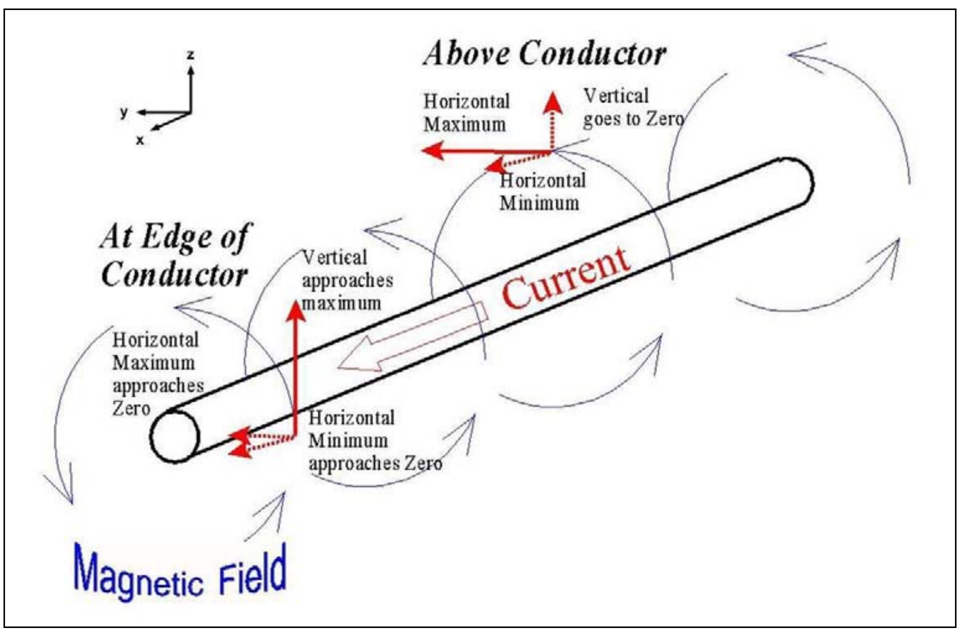


Figure 11 – Electric Current and Magnetic Field Wire Model

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A magnetic field is produced from the electric current flow through the wire. This magnetic field circles the wire (known as the right hand rule). By analyzing the strength of the magnetic field in terms of its two horizontal vector components (x, y) and its one vertical vector component (z) as a function of distance from the wire, the following information can be noted:

- Directly above the energized wire (12:00 o'clock), the horizontal maximum (x) component of the magnetic field is at its maximum. The vertical (z) component approaches zero.

- Directly to either side of the wire (3:00 or 9:00 o'clock), the horizontal maximum (x) component of the magnetic field approaches zero. The vertical (z) component is at its maximum.

- The horizontal minimum (x and y) components are always at a minimum or zero in a plane that has the same elevation (z value) as the wire.

- The direction of electrical current flow in the ground represents the orientation of the groundwater channel and is indicated by the direction perpendicular to the maximum horizontal magnetic field. In this case, for example, the magnetic field directly above the flowpath is in alignment with the y-axis, while the current flow direction is in alignment with the x-axis.

- The rate of change of the vertical magnetic field intensity with distance across the anomaly is proportional to the width of the current path and indicates the width of the groundwater channel. Width of the horizontal magnetic field is proportional to depth and width of the channel. Correlation of vertical and horizontal data can be used to clarify ambiguities of width and depth.

In this simplest case, such as a wire-like conductor or small channel under the earth's surface, the magnitude of the horizontal x-y component will locate the conductor and the vector direction will help determine its orientation. The z-component—although less helpful due to the observation points being confined to the space above the ground surface (always above the electric current sources)—can still help in some situations to determine the depth and size of the conductor.

8. Modeling with Finite Element Flow Paths

Given the basic modeling principles discussed above, the modeling process begins by preparing magnetic field maps which are created from the reduced and normalized x and y vector components of the measured and recorded magnetic field data. These magnetic field maps or "footprint" maps, as they are often referred to, show a plan view of the contrast between areas of high electrical conductance (electric current concentration or flow) and areas of low electrical conductance (see Figure 12 below).

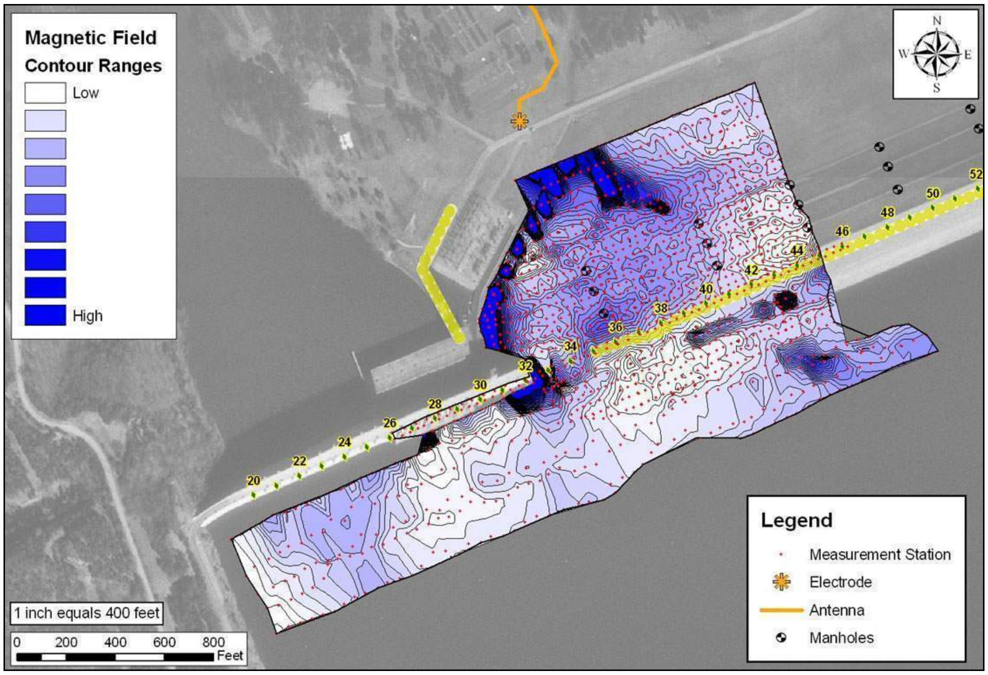

Figure 12 – Horizontal Magnetic Field Map

The areas of high electrical conductance are interpreted as areas where groundwater is likely concentrating in the subsurface or is flowing along cultural features. Nothing more should be construed from the magnetic field contour lines. The AquaTrack technology best identifies the contrast between areas of high conductance and low conductance. If no abnormal patterns or anomalies are found between high and low areas of conductance, then it is because the electric current in the energized space is dispersing uniformly. If there are anomalies between high and low areas of conductance, then these areas can be identified, mapped and modeled.

The magnetic field contour lines are shaded to help distinguish highs from lows. The shaded contour lines represent "relative" strength of the magnetic field. The AquaTrack technology uses relative magnetic field contours to visualize current flow, in contrast to a topographic map, that uses elevation contour lines that have a bench mark for standardization (e.g., elevation 0 = sea level). To achieve standardization for magnetic field strength for the AquaTrack technology would be very difficult because of the highly variable conditions of each survey (antenna / electrode configurations, voltage and current requirements, geologic conditions, etc.). The magnetic contour lines shown in the "footprint" maps are provided simply for comparison purposes to one another to determine where electrical current flowing in the study area concentrates and gathers—thus the term "footprint" maps.

The shape of the magnetic field contours is critical to identifying preferential flow paths in the subsurface. To the untrained eye, reading these magnetic field contour maps is similar to reading or interpreting a topographic quadrangle map. The higher elevations (which form ridges and mountain tops) and the lower elevations (which form valleys) are often times the pathways along which roads and/or trails are constructed. These are the paths of least resistance to traverse. The same holds true for interpreting the AquaTrack contour maps. The highs (ridges and mountain tops) in the magnetic field contours form pathways of least resistance for the electrical current to follow. By identifying these high points and ridges and connecting them together through the earthen embankment, the horizontal position of preferential flow paths can be identified (see dark blue lines in Figure 13). The accuracy of these flow paths' horizontal position is approximately one-half of the station spacing. For instance, if measurements were made on a 10-meter by 10-meter grid, then flow paths could be identified to within 5 meters of their actual positions.

Because the magnetic field measurements are limited to the surface of the earth, it is much more difficult to determine with any degree of accuracy the vertical position of the electrical current flow paths. The shape or gradient along the edges of anomalies in the footprint map can give clues to the depth of the source current—whether it is relatively shallow or deep, but better methods are in the process of being developed to provide more accurate estimates of depth of flow.

Due to the difficulty involved in determining vertical positions of current flow, theoretical finite element electric current flow models are constructed in the MATLAB™ programming environment to simulate the magnetic field response from these flow models. In geophysical terms, the method is called Forward Modeling, and it often requires many trial-and-error adjustments to the model until it begins to fit or match the given physical data.

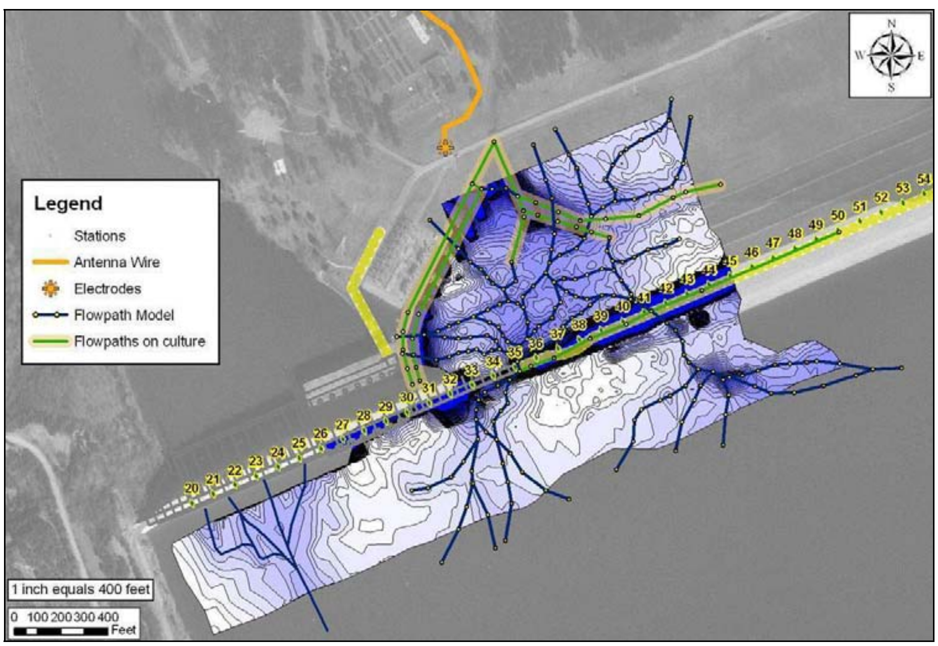

Figure 13 – Electric Current Flow Path Model

A typical 3D model of a project includes the topographic surface of the site, which is based on spatial coordinates obtained from GPS data taken at each station and/or from digital elevation models that may or may not be available. Probable groundwater flow paths, which are identified from the magnetic field "footprint" maps (Figure 13), are re-created in the model and are

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adjusted in depths and intensities to simulate the magnetic field through forward modeling (see Figure 14).

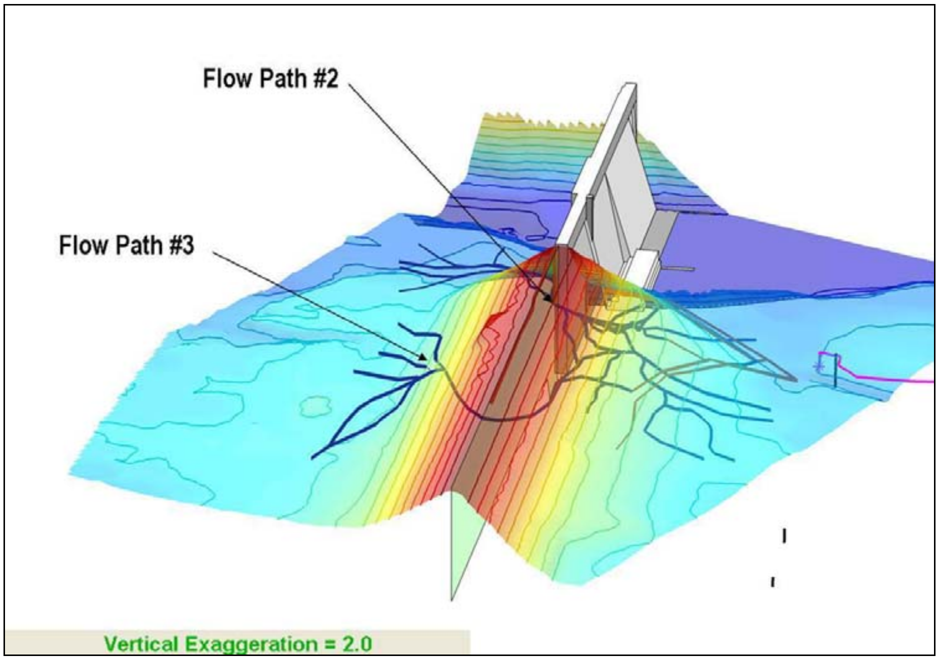


Figure 14 - Typical 3D Model

After subsurface flow paths have been identified in the footprint map, a simulated electrical current—similar to that applied to the antenna in the AquaTrack survey—is applied and distributed throughout the finite element wire model to simulate the magnetic field created by the current flow in the earthen embankment. Figure 15 shows an example of the theoretical magnetic field contours (red lines) matching closely with the anomalous shapes in the AquaTrack footprint map (blue shades).

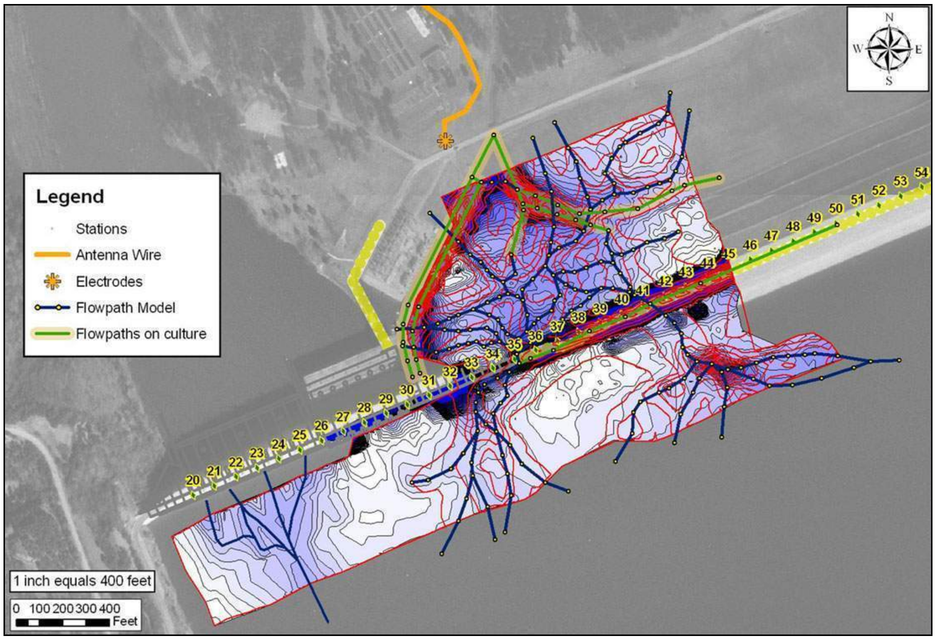


Figure 15 – Theoretical Magnetic Field Map

In order to match the computed theoretical magnetic field with the AquaTrack (physical) magnetic field, the intensity and the position of the finite element wire model is adjusted until an approximate match between the theoretical and physical magnetic fields are obtained (forward modeling – trial and error process). Figure 16 portrays an example of an anomaly produced from a metal pipe beneath the crest of an embankment. The theoretical magnetic field is simulated with flow paths at four different depths—Model 1 being the shallowest and Model 4 being the deepest. The four theoretical magnetic field anomalies are shown on the upper plot. The shape of the Model 2 signal response fits the AquaTrack data very closely; hence, it is concluded that the pipe elevation is about 134 meters. In this case, the true elevation of the pipe was known to be very close to 134 meters, so the model proved to work very well in simulating a pipe.

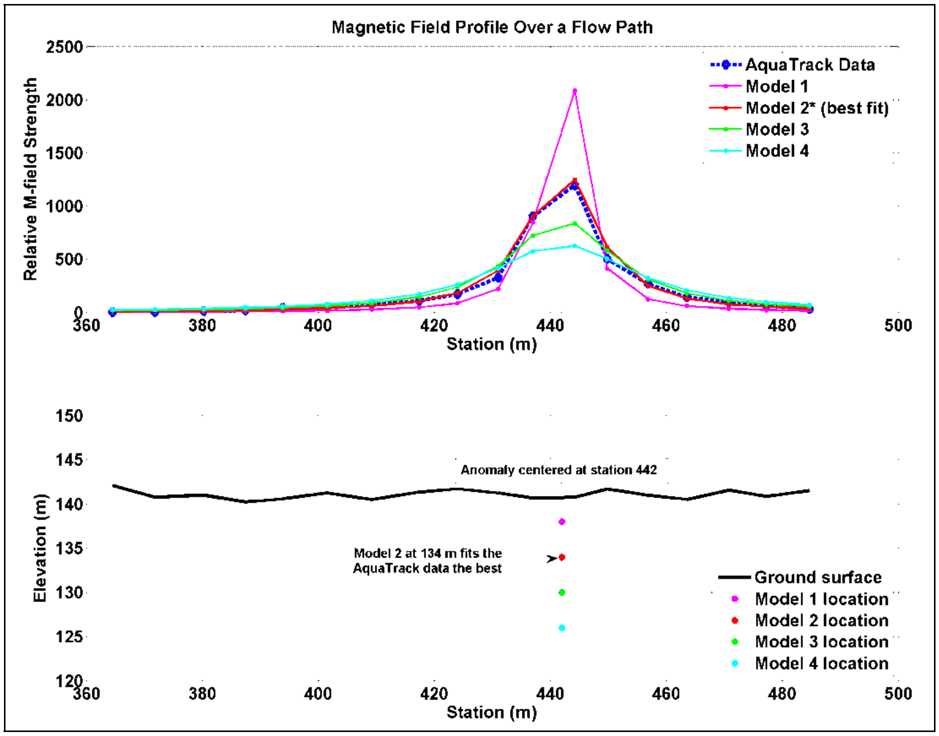


Figure 16 – Determining Depth of Flow Path by Modeling

In most cases, the model—although a simplified representation of groundwater flow—represents a probable solution of the subsurface flow through, beneath or around the embankment. It does not necessarily represent the only solution. For example, it is possible for a tightly focused flow path at depth—say 60 feet below the ground—to produced a very similar magnetic field response to a broader, more widespread channel of electric current flow that is shallower—say 35 feet deep. Distinguishing between these two scenarios can sometimes be difficult using the finite element flow path model alone.

Site-specific information can help to impose boundary conditions that constrain the model and reduce the propensity of improbable solutions. Examples include: (1) geologic conditions (location and depths of varying soil and rock types); (2) as-built drawings of earthen embankment (depth of cutoff trench, foundation conditions, construction material and zones, etc.); (3) hydrogeologic conditions (piezometric surface, seep locations, etc.); and (4) any other information pertinent to the investigation. The modeling results, along with information that imposes boundary conditions, can result in a probable solution as to where and how seepage flows through earthen embankments.

It is highly probable that the subsurface flow is much more complex than can be shown in these simple theoretical electric current models. The theoretical modeling demonstrates that the AquaTrack data can provide reasonable solutions as to how water seeps through, beneath or around earthen embankments

9. Interpretation

The reduced data, as well as known magnetic field interferences, are then presented on contour maps and/or in profile data plots. These maps and profiles are generally shown superimposed upon or in conjunction with aerial photographs and/or CAD drawings (plan or cross-section) to help aid in the interpretation of the data. Aerial photographs and CAD drawings are geo-referenced to ensure correct placement of magnetic field measurement stations and magnetic field intensities on the base maps. Any identified cultural features relative to the survey are highlighted to aid in interpretation of the data. Any additional geological and hydrogeological information pertinent to the study is also integrated.

The maps (e.g. Figure 15) help identify probable seepage flow paths through an earthen embankment which include the magnetic field footprint map (blue shading), the finite element flow path model (shown as dark blue lines), and the theoretical magnetic field (shown as red contour lines). The small yellow circles on the modeled flow paths indicate nodes. The flow path elevations are turned off in this particular view to simplify the drawing. The information can also be shown in 3D views to better visualize seepage beneath an embankment (see Figure 17 below).

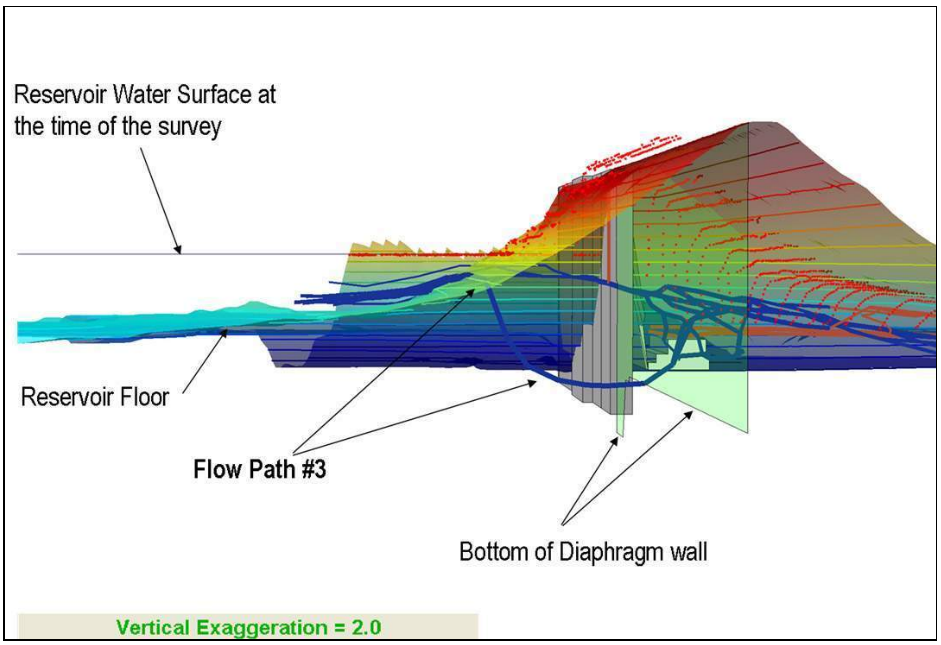


Figure 17 – 3D Model, Isometric Cross-Sectional View of Seepage Through Embankment

Included in these 3D views of the embankment are surface and subsurface cultural features that aid in the interpretation and characterization of subsurface flow paths. The information contained in these final maps and models are normally compared with known information of the site to further characterize and substantiate subsurface conditions impacting seepage flow beneath the area of investigation

10. Conclusions

The interpretation of the electric current flow, which reveals groundwater flow paths, is based upon widely known and accepted scientific theory and principles; however, in practice it can be quite complex. Proper interpretation of the data requires an understanding of site geology, groundwater physical principles, sound electromagnetic theory and experience working with and developing the technology. A great deal of effort has been put forth to eliminate error in the data collection, data reduction / normalization and interpretive process. As with any technology (especially new technologies) there is always room for improvement. Without exaggeration, the "*Willowstick*" instrument, data collection, reduction, and modeling processes improve daily.

The accuracy of the technology and its margin for error are yet to be fully quantified. As of the date of this paper, the technology has proven to be very helpful in confirming seepage problems as well as guiding characterization efforts in a much more rapid pace. The AquaTrack survey method and grid spacing of measurement stations is intended to provide a general characterization of the seepage flow through an earthen embankment and cannot provide highly detailed and exact characterizations; rather, the technology is viewed as a means to guide and direct traditional subsurface exploratory work in order to improve groundwater characterization efficiencies (cost and time) and to arrive at conclusive and quantitative answers about a specific seepage problem. The technology is not viewed as a means of providing absolute answers with calculated margins of error, risk or vulnerability classifications. For example, the GPS survey equipment used in the AquaTrack investigation methodology generally has one meter horizontal accuracy and three meter vertical accuracy. The combinations of topography and canopy cover over and around a site can reduce the accuracy of GPS measurements. GPS elevations can sometimes vary by several meters or more. When survey data is observed to be inaccurate, corrections are made to the data as best as possible from digital elevation models (DEM) or from averaging between data points believed to be representative of the area in question. Also, the modeling process is very simplistic and very much in its infancy. All of these things can and will improve as the technology is put to task.

The results obtained from an AquaTrack geophysical investigation is to be used to make informative decisions concerning how to further confirm, monitor and possibly remediate seepage through, beneath and around an earthen embankment before it reaches unacceptable proportions. The information contained in the AquaTrack methodology should be compared with known information or it should be used to target areas to obtain information in effort to fully characterize a site. There is no technology better suited for this assignment.

APPENDIX E – PROFESSIONAL BIOGRAPHIES

VAL O. KOFOED, P.E.

President / Principal Engineer

Education

- B.S. – Civil Engineering (1983)
  Brigham Young University, Provo, UT

Professional Experience – 27 Years

- Willowstick Technologies, LLC 2004 – present

President and Consulting Engineer. Responsible for daily operations of all groundwater characterization investigations.

- Sunrise Engineering, Inc. 1983 – 2004

20 years experience as a Consulting Engineer. Principal Engineer from 1987 to 2004. Responsible for Hydrogeology Division and water resource engineering related projects.

- Western Utility Contractors 1982 – 1983

$1^{1}/_{2}$ years experience as Project Engineer. Estimator and Project Engineer on water resource construction projects.

Registration

- Registered Professional Civil Engineer
  Utah (#172947)
  Arizona (#20923)

JERRY R MONTGOMERY, PH.D

Inventor, AquaTrack Methodology / Consulting Geophysicist

Education

- Post Doctoral Studies – Geostatistics (1974)
  University of Leeds, Leeds, England
- Ph.D. – Geophysics (1973)
  University of Utah, Salt Lake City, UT
- B.S. – Physics (1965)
  Weber State University, Ogden, UT

Professional Experience – 42 Years

- Willowstick Technologies, LLC 2004 – 2010

Chief Geophysicist. Assisted in spinning off the AquaTrack technology and Hydrogeology Division from Sunrise Engineering into it own business unit (Willowstick). Responsible for interpretation and further improvement of the AquaTrack hardware and software including other new groundwater mapping technologies.

- Sunrise Engineering, Inc. 2001 – 2004

Research and Development Director. Responsible for improving the AquaTrack technology, taking it from an analog to a digital technology.

- Self-employed 1996 – 2001

Inventor and patent of the AquaTrack technology. Conducted contracted AquaTrack surveys.

- Bureau of Mines 1990 – 1996

Staff Scientist and Researcher. Involved in bio research for removal of heavy metals. Developed electromagnetic tracking and monitoring equipment for monitoring groundwater plumes, biological process, and in-situ leaching.

- U.S. Army, Dugway Proving Grounds 1986 – 1990

Operations Research Analyst. Served as Contracting Officers Representative for diverse contracts. Devised unique technique for analyzing time dependent data and helped developed NBC projection for M1 tank, Apachy, LCAC's and C117's.

- ASARCO, Inc. 1968 – 1986

Chief Geophysicist. Responsible for organization, direction and interpretation of geophysical surveys. Developed programs to study minerals, groundwater and environmental problems. Developed new geophysical technologies and expanded theories to implement and improve geophysical interpretation.

RONDO N. JEFFERY, PH.D

Consulting Physicist

Education

- Ph.D. –Physics (1970)
  University Illinois – Urbana/Champaign
- M.S. – Physics (1965)
  Brigham Young University, Provo, UT
- B.S. – Physics (1963)
  Brigham Young University, Provo, UT

Professional Experience – 30 Years

- Willowstick Technologies, LLC 2004 – 2010

Physicist. Assists Dr. Montgomery with all aspects of research and development. Responsible for the electronic design and construction of the AquaTrack receiver.

- Weber State University 1980 – present

Professor of higher education and research. Taught courses in electronics, solid-state physics, engineering physics, nuclear physics lab, and astronomy. Participated in numerous research and development projects. Authored many publications and presentations.

MICHAEL L. JESSOP

Geophysicist

Education

- M.S. – Geophysics (2005)
  University of Utah, Salt Lake City, UT

- B.S. – Geophysical Engineering (2002)
  Montana Tech, University of Montana, Butte, MT

Professional Experience – 8 Years

- Willowstick Technologies, LLC 2005 – present
  Staff Geophysicist. Responsible for data analysis & modeling using MATLAB™ programming package to understand probable groundwater flow paths observed in the AquaTrack data. Assists with data interpretation and quality control.

- Gradient Geophysics, LLC 2002 – 2003
  Geophysics Field Crew. Worked with and directed crews on geophysical field surveys including resistivity, IP, and magnetic data acquisition.

MICHAEL WALLACE

Geophysicist

Education

- M.S. – Geophysical Engineering (2006)
  Montana Tech, Butte, MT
- B.S. – Physics (2003)
  Hampden-Sydney College, Hampden-Sydney, VA

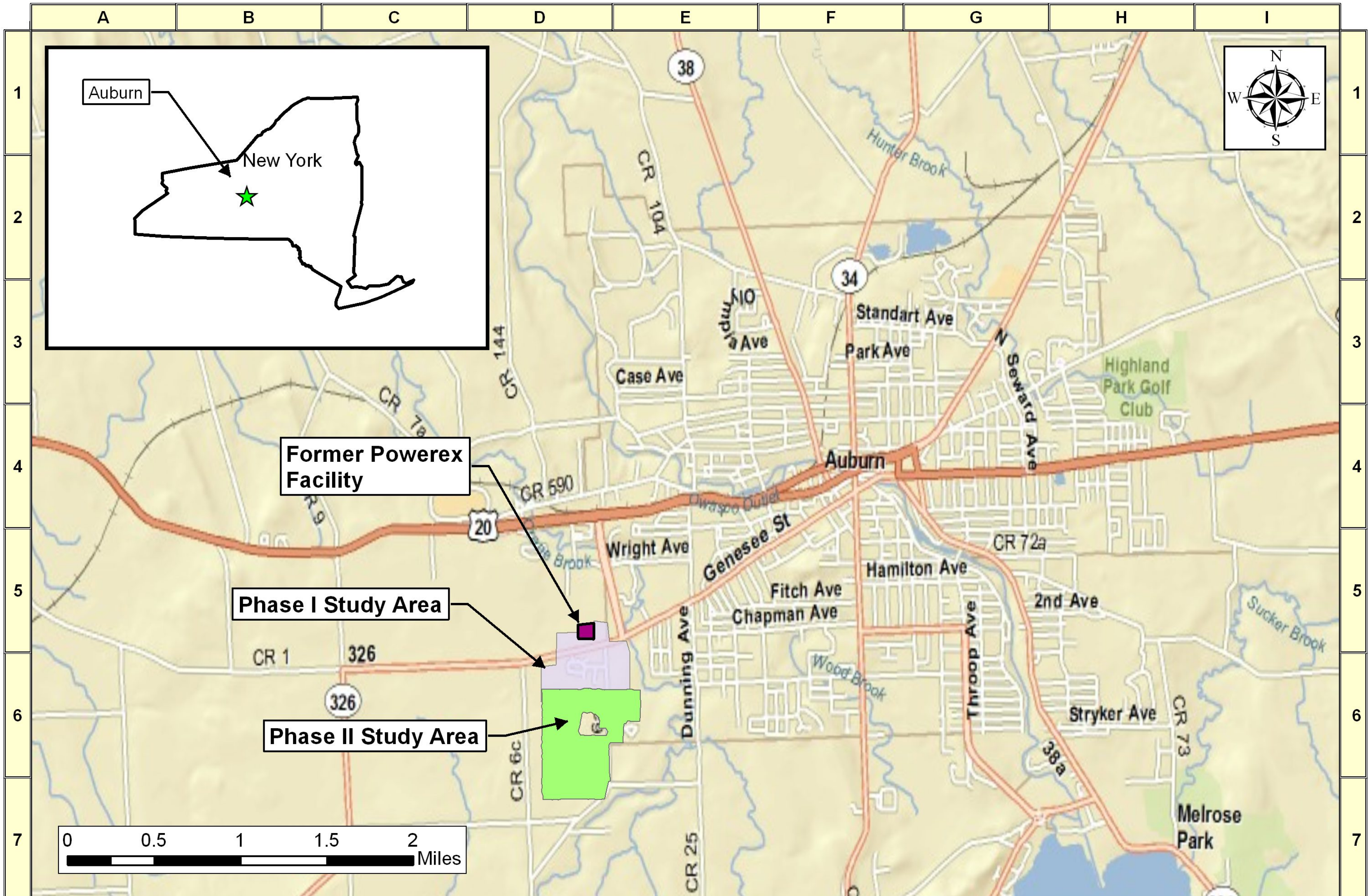
Professional Experience – 5 Years

- Willowstick Technologies, LLC April 2006 – present
  Staff Geophysicist. Responsible for initial data interpretation and data quality control. Also responsible for Reduction program and Field program. Assists in modeling using MATLAB program and with data interpretation.

- Curtin University Exploration Geophysics Department, Perth WA 2004
  Exchange Student. Assisted with land seismic, seismo-electrics, and Time Domain EM surveys over gas reservoir. Built portable audio magnetotelluric survey system.
- Sweet Briar College 2003
  Student Research Intern. Processed radio astronomical data in search of circular polarization in active galactic nuclei.

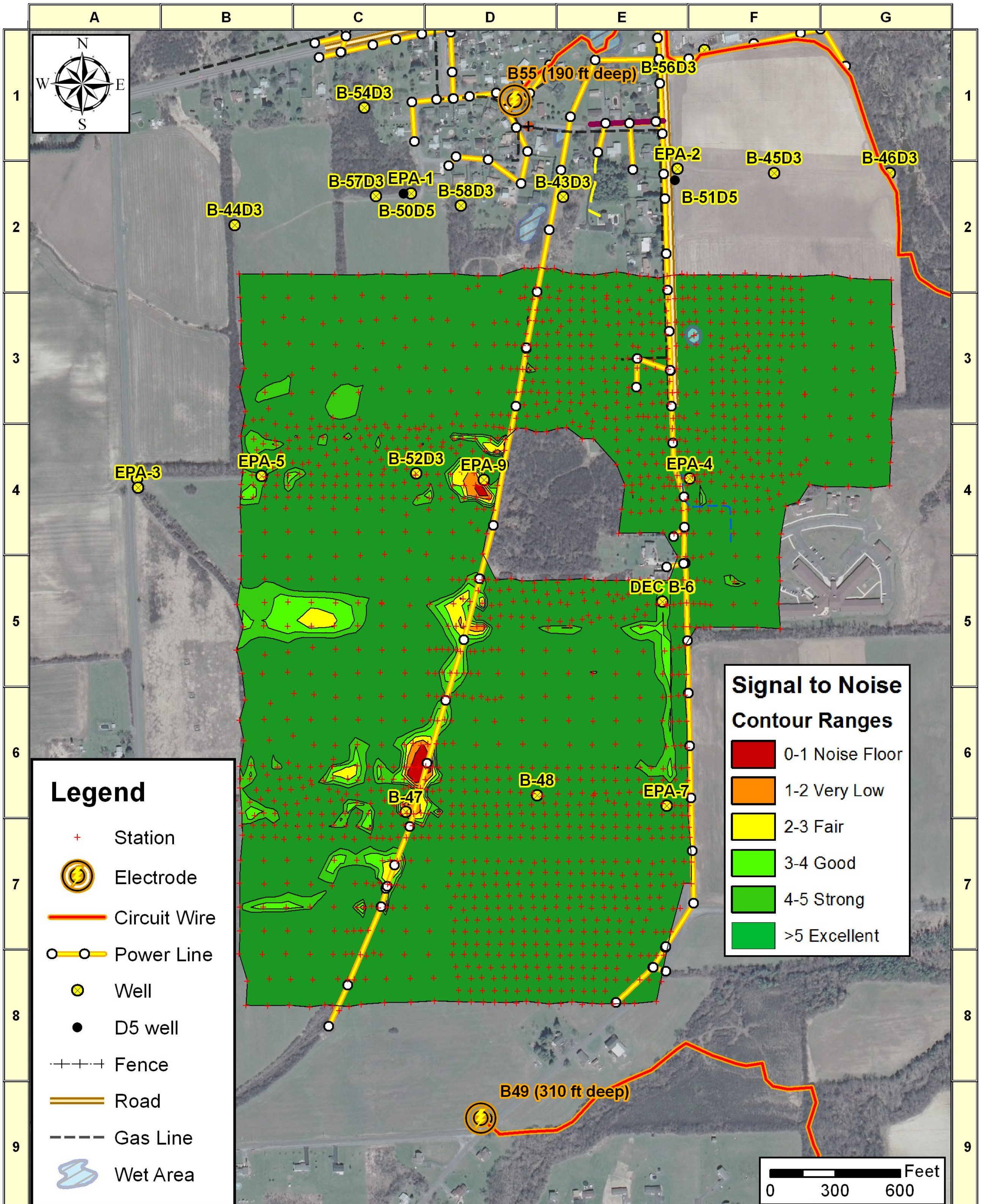
- Hampden Sydney College 1999 – 2003
  Student Research Assistant. Tested amplifier circuits for X-Ray fluorescence spectrometer, cleaned and tested cryostat and vacuum system. Developed scripts in Python and AWK to automate astronomical observations in small radio telescope

- National Radio Astronomy Observatory 2001
  Engineering Intern. Worked with Metrology Group on active projects and developed low level control software for HP Laser Measurement System.



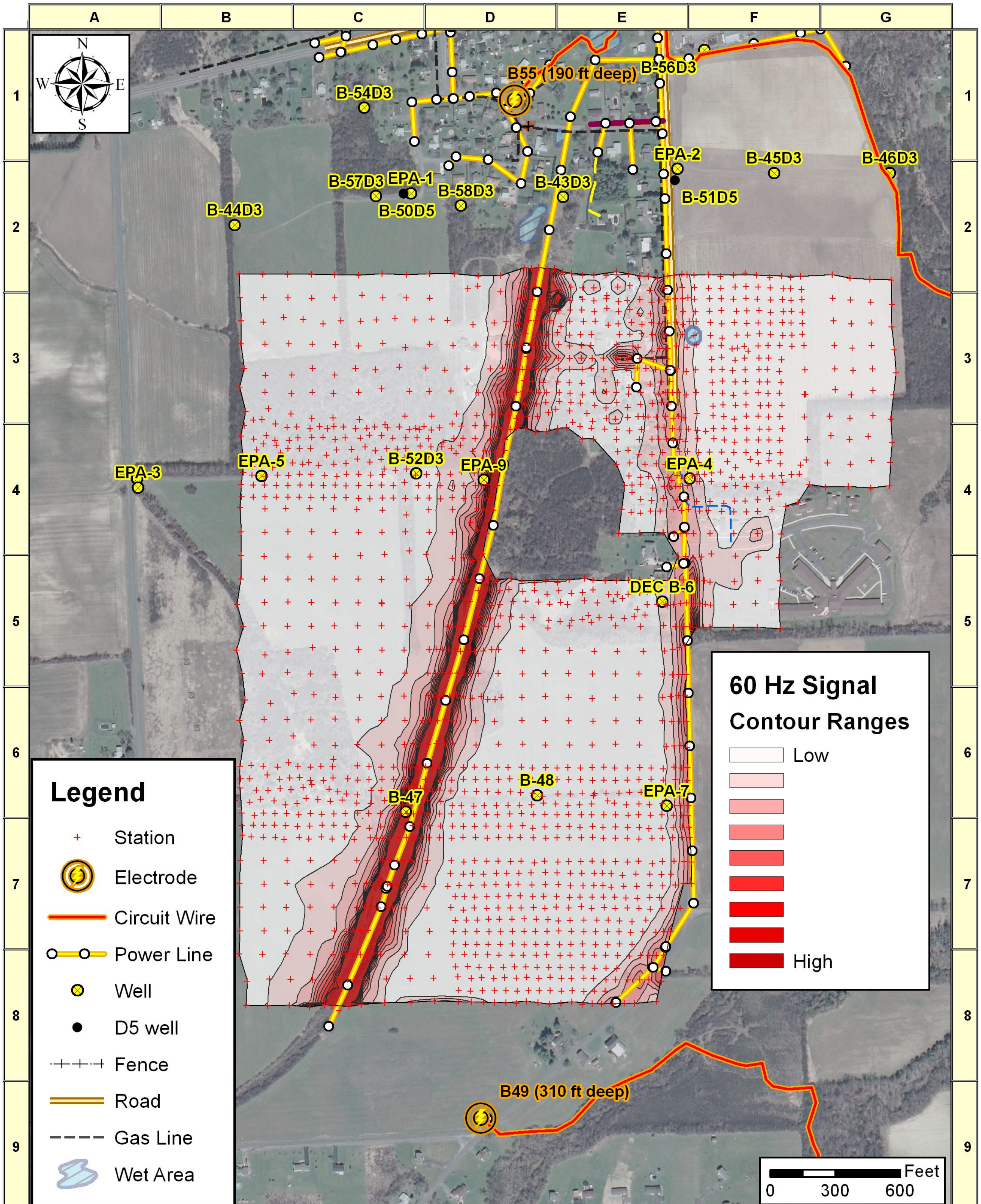
WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure G1 - Project Location	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:50,000

R2-0025111



WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure QC1 - Signal-to-Noise Map	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:7,200

R2-0025112



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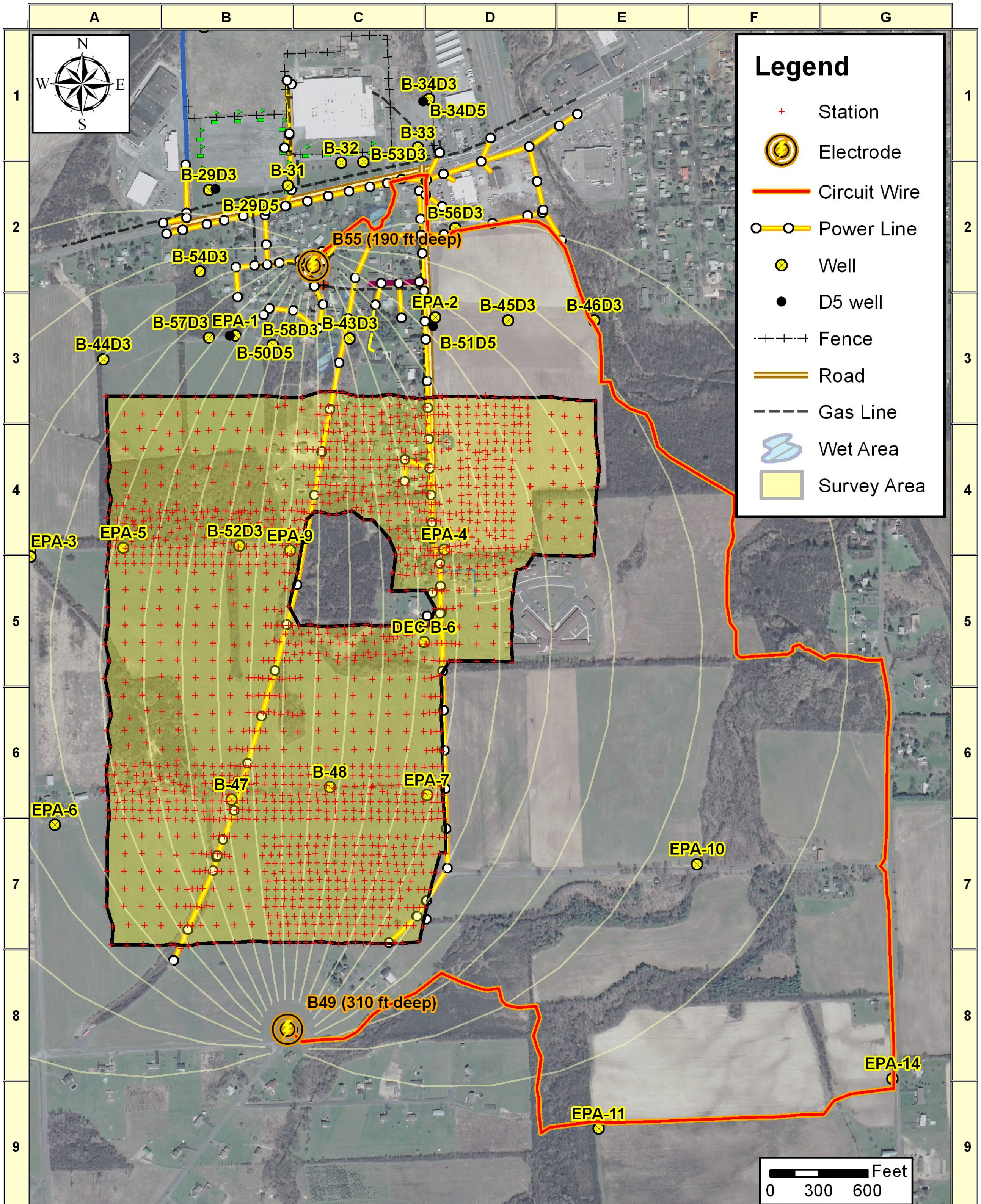
R2-0025113



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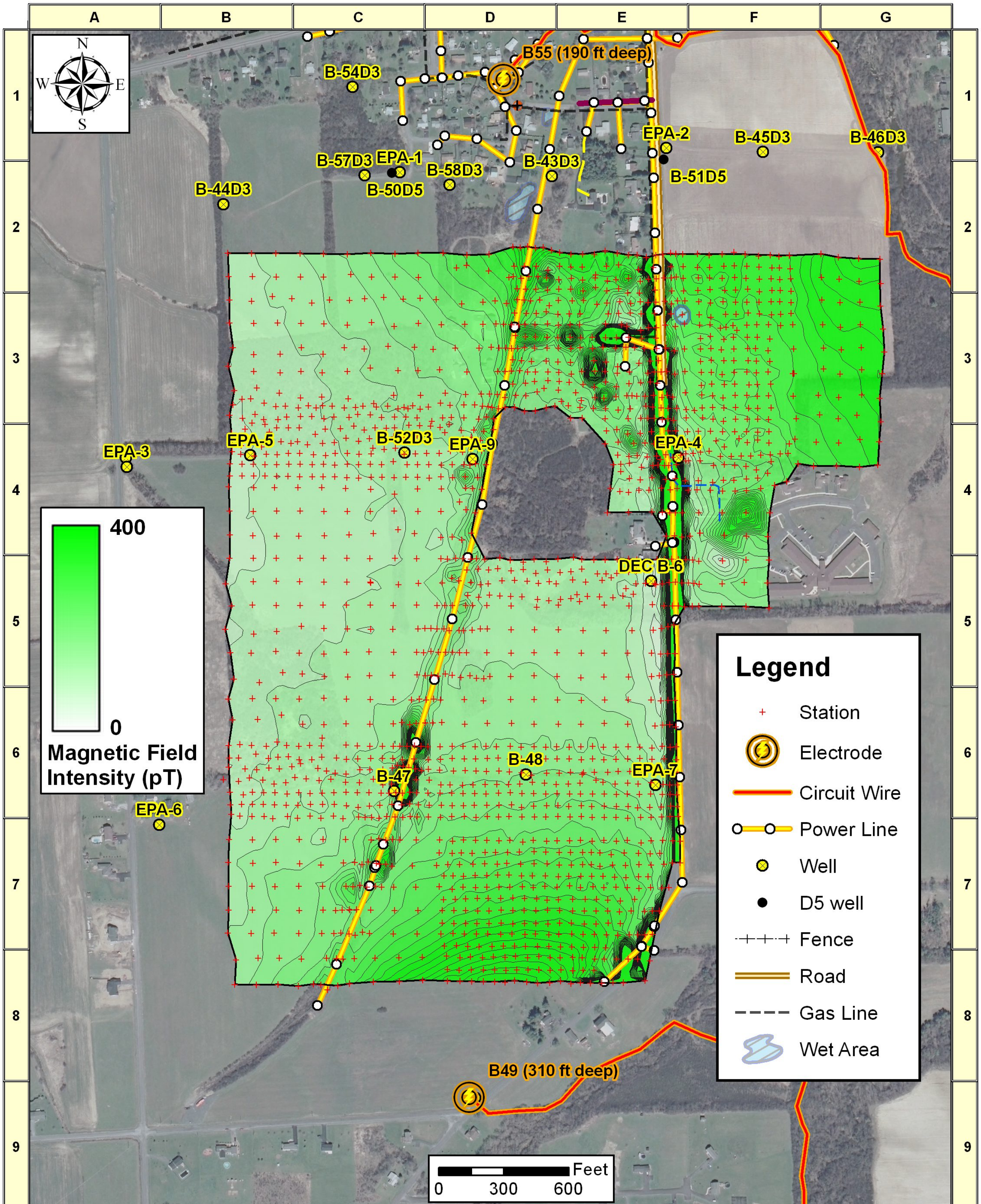
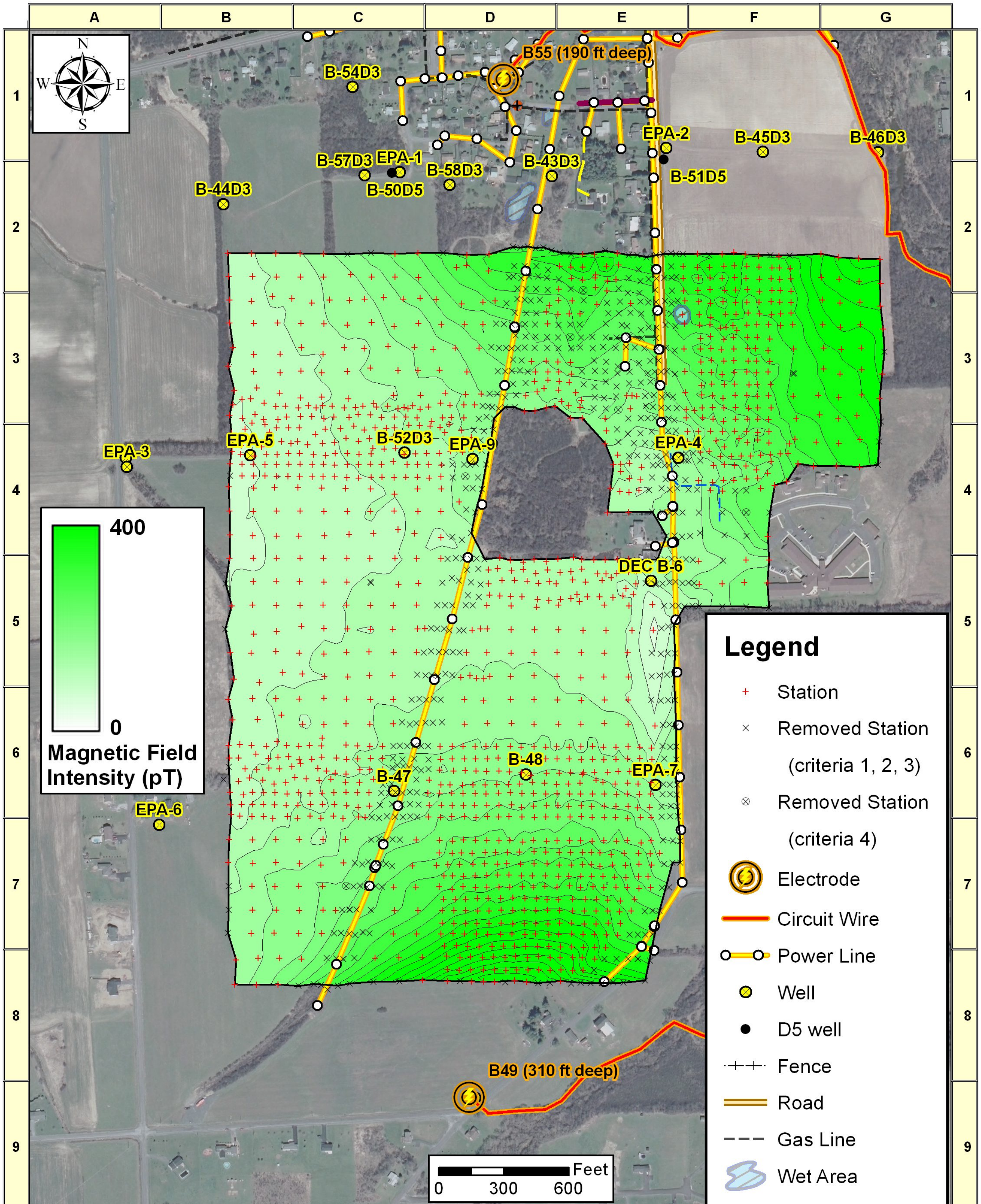
R2-0025114



WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure 1.2 - Magnetic Field Map	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:7,200

R2-0025115



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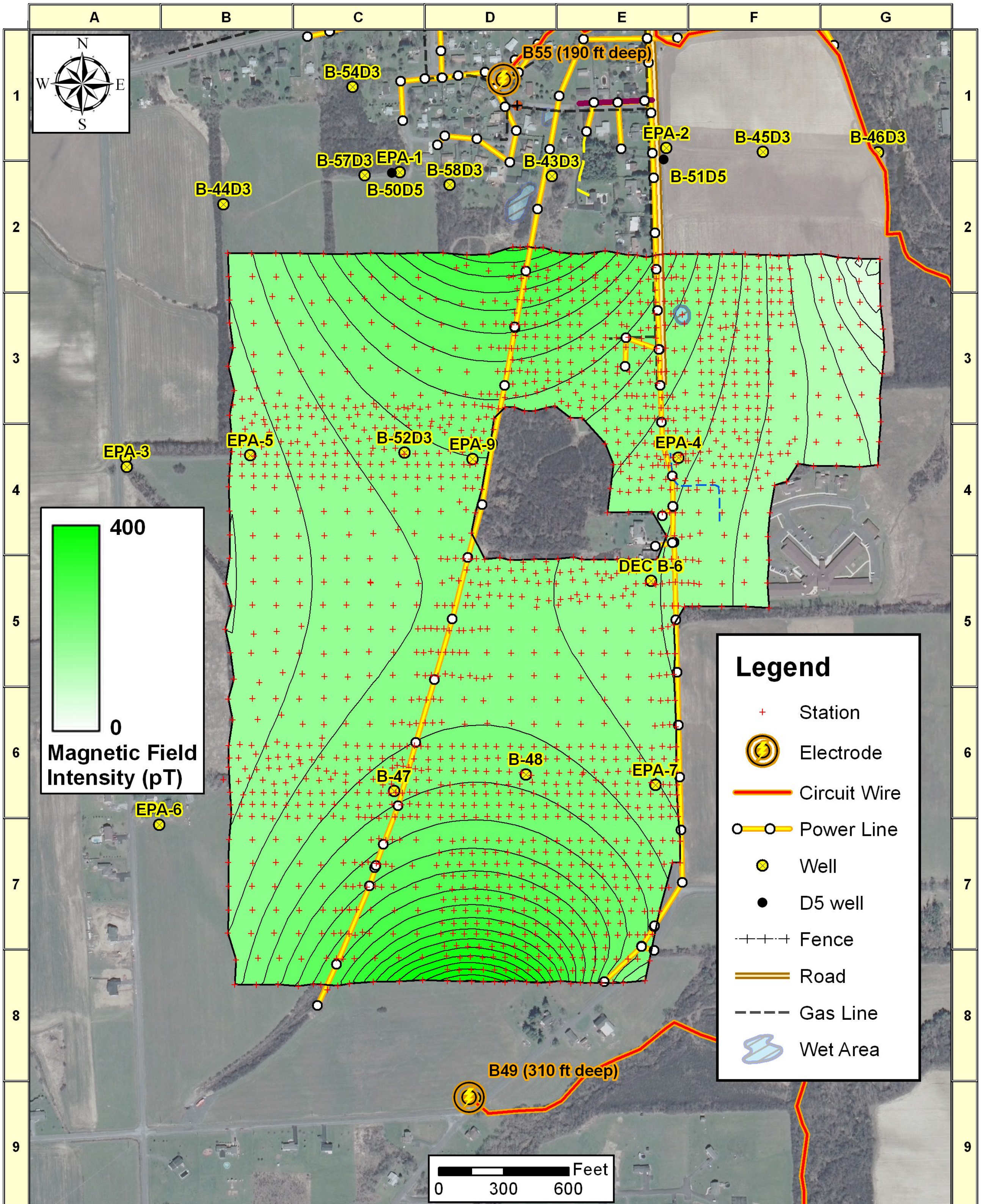
R2-0025116



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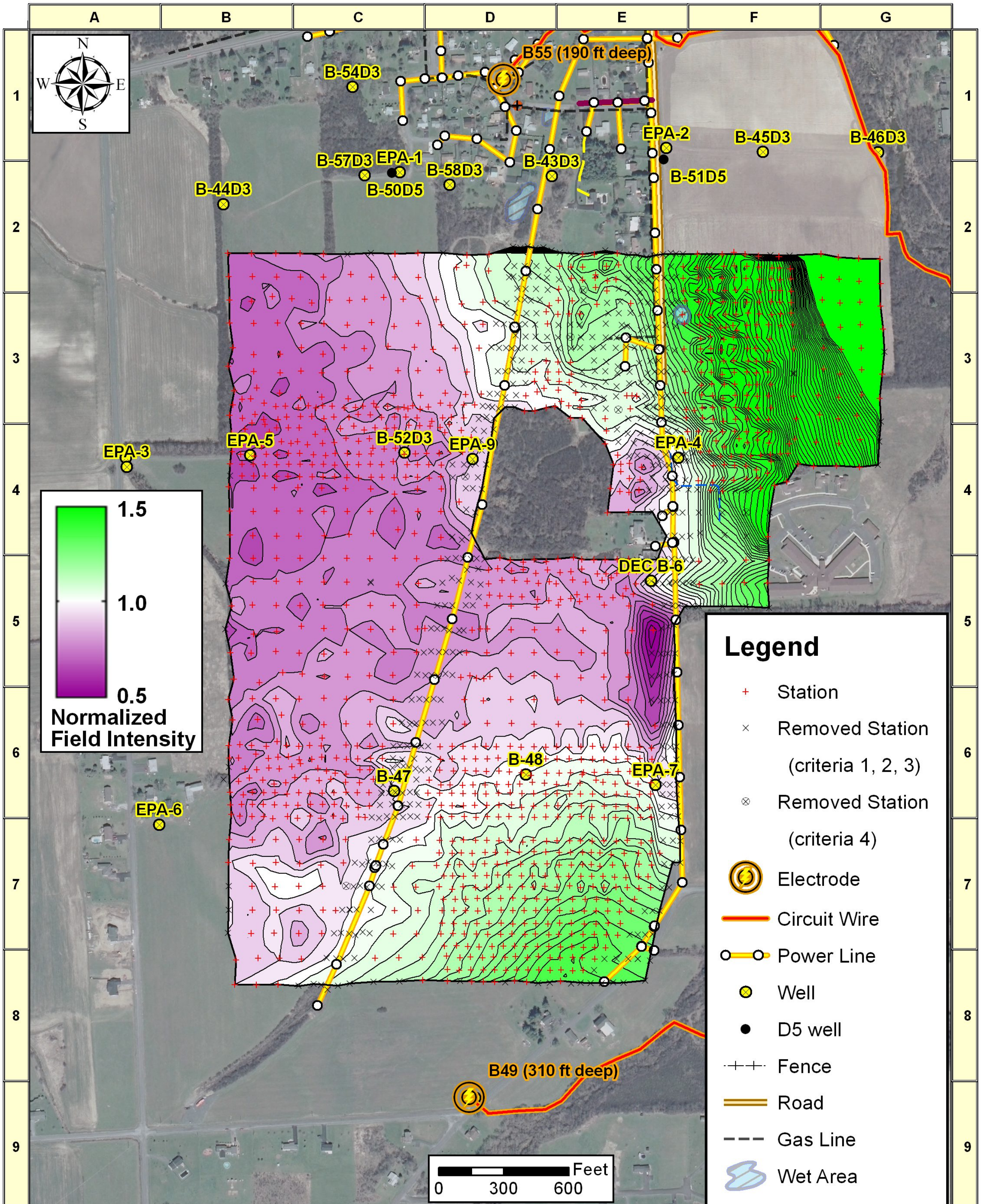

WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure 1.5 - Ratio Response Map	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:7,200

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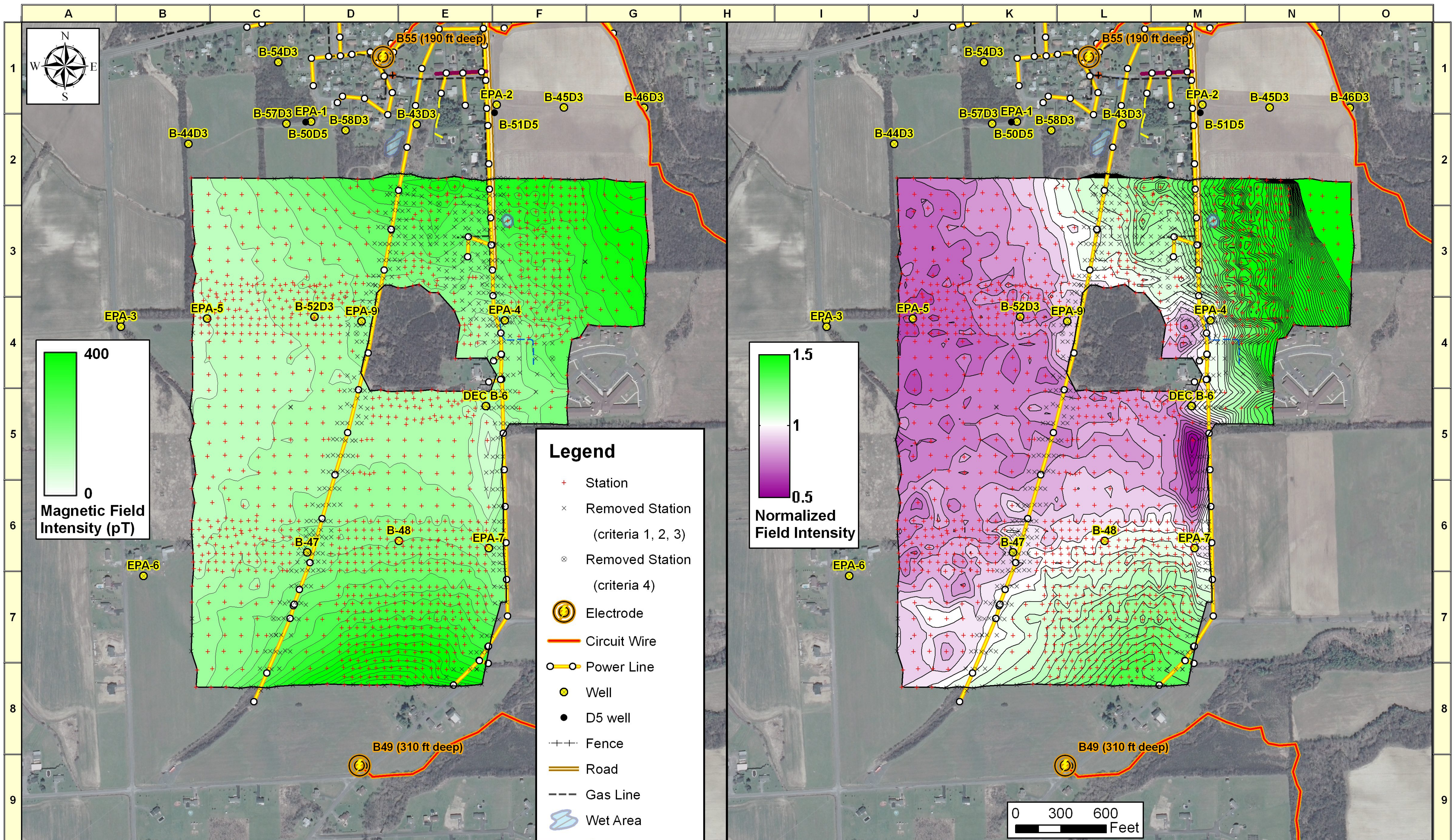

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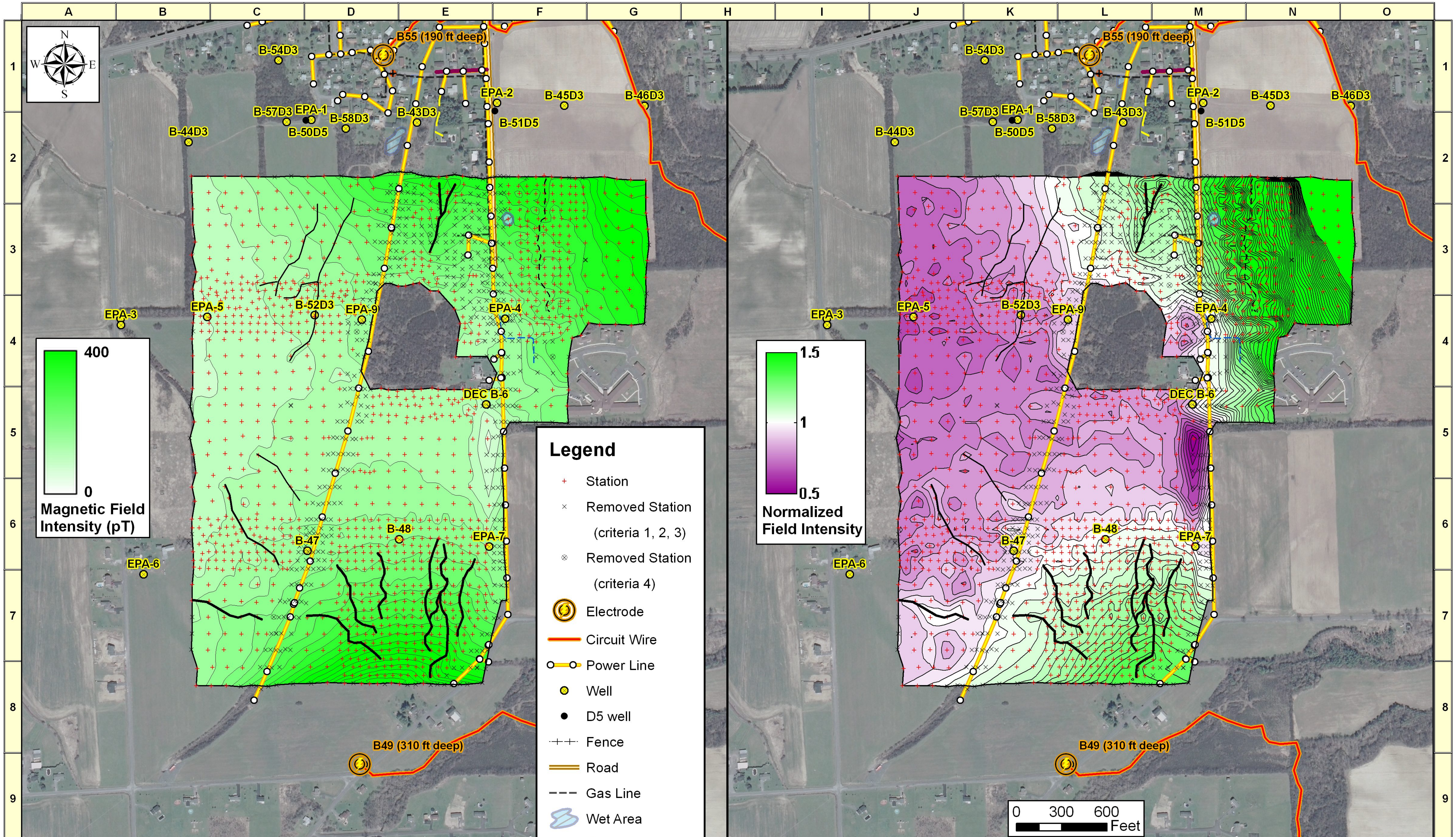

WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure 1.7 - Comparison of Filtered M-field Map and RR Map with Potential Flow Paths	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:7,200

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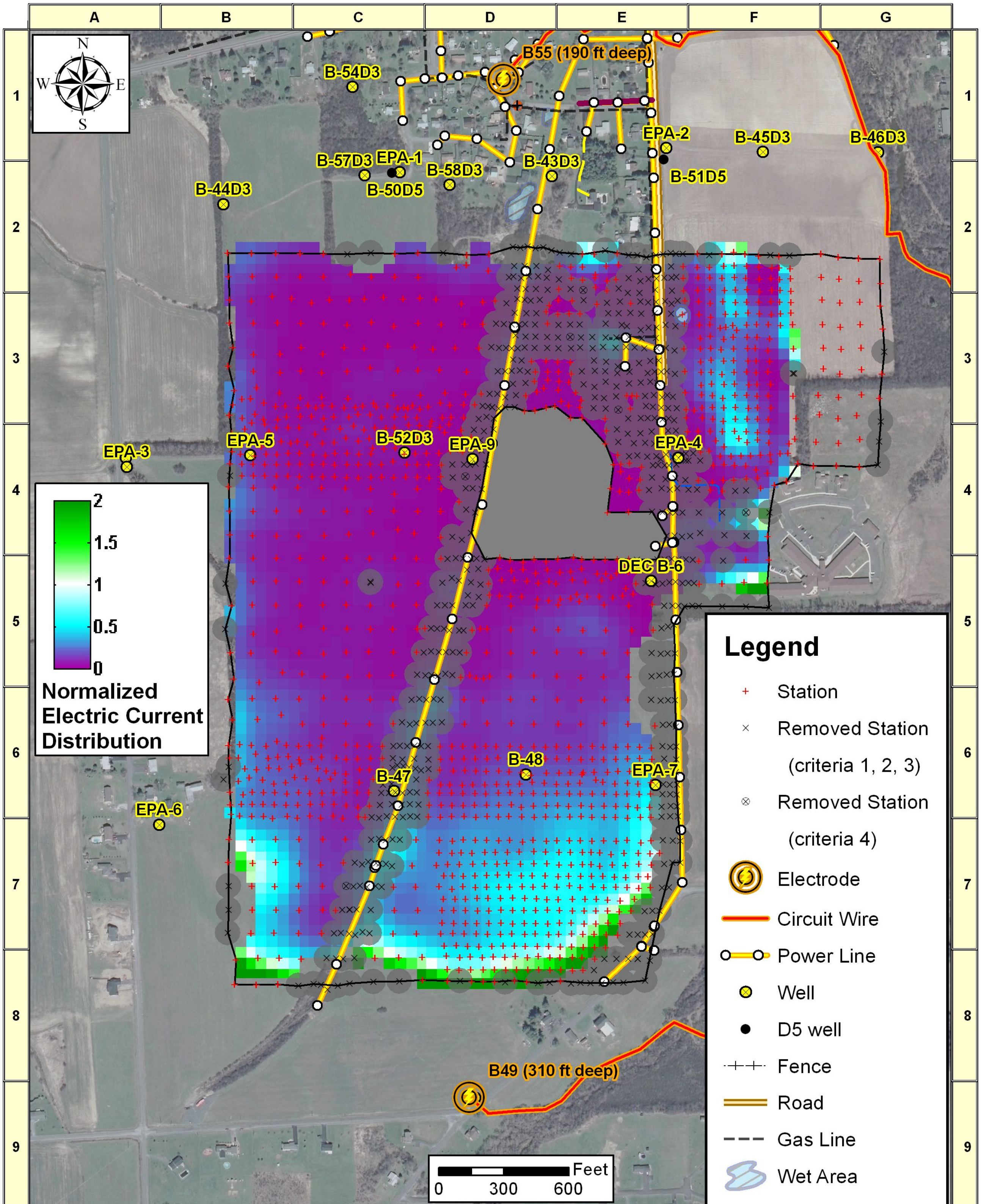
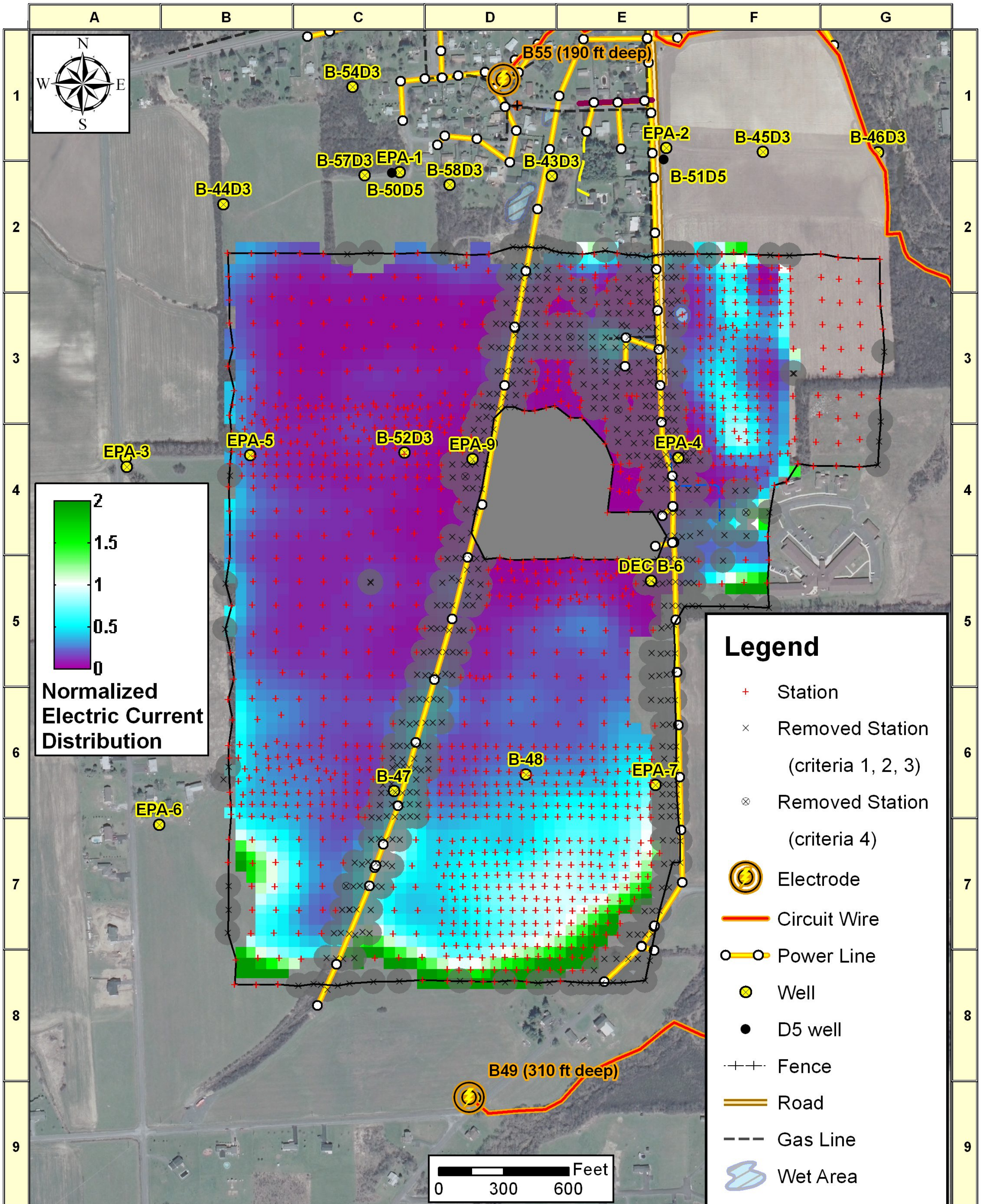


WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure 1.8 - ECD Model Slice Taken 40 Feet Above D3 Zone	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:7,200

R2-0025121



WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure 1.9 - ECD Model Slice Taken 20 Feet Above D3 Zone

PROJECT #:	10106
DATE:	29-July-2011
SCALE:	1:7,200

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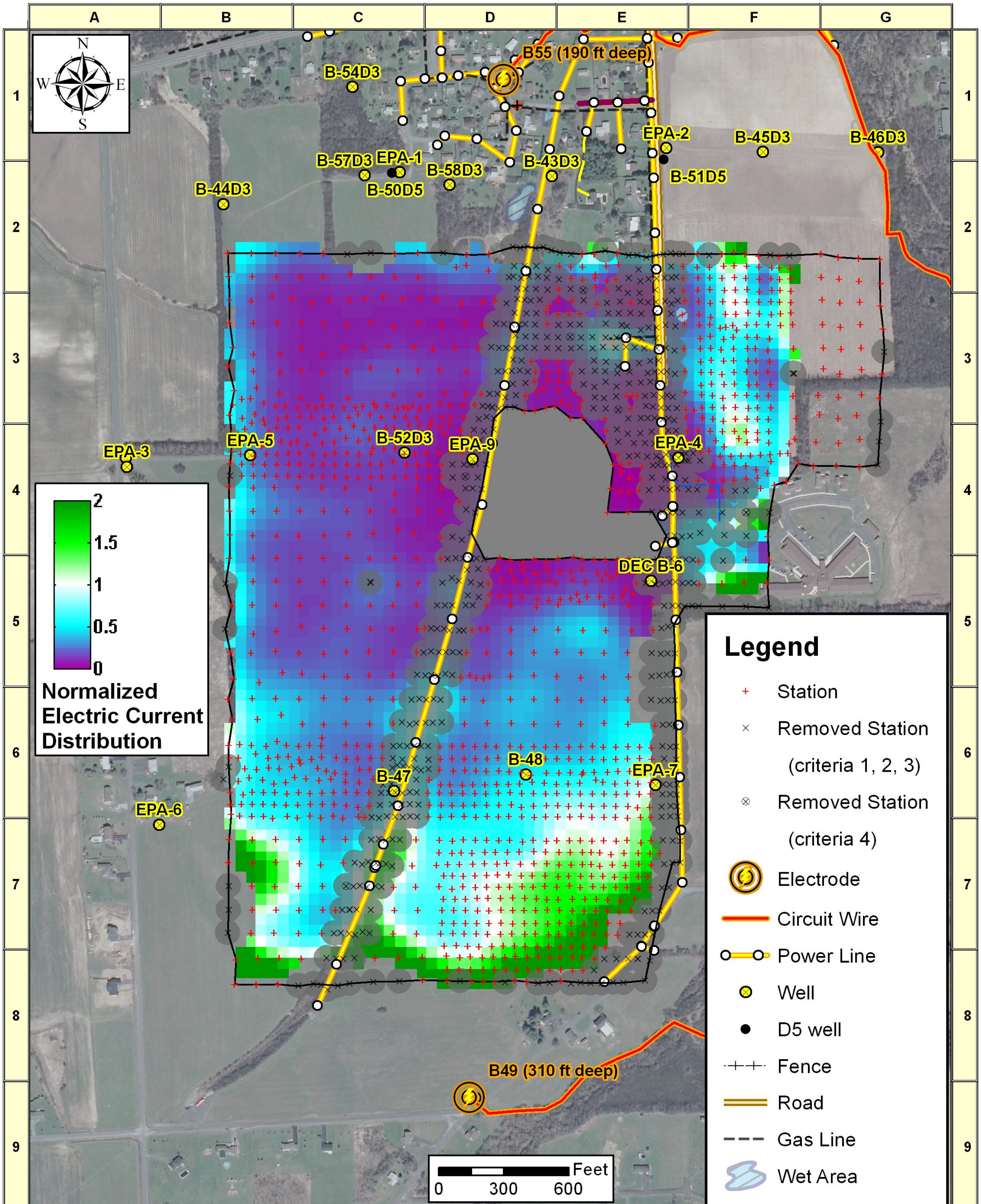

WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure 1.10 - ECD Model Slice Taken Within D3 Zone	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:7,200

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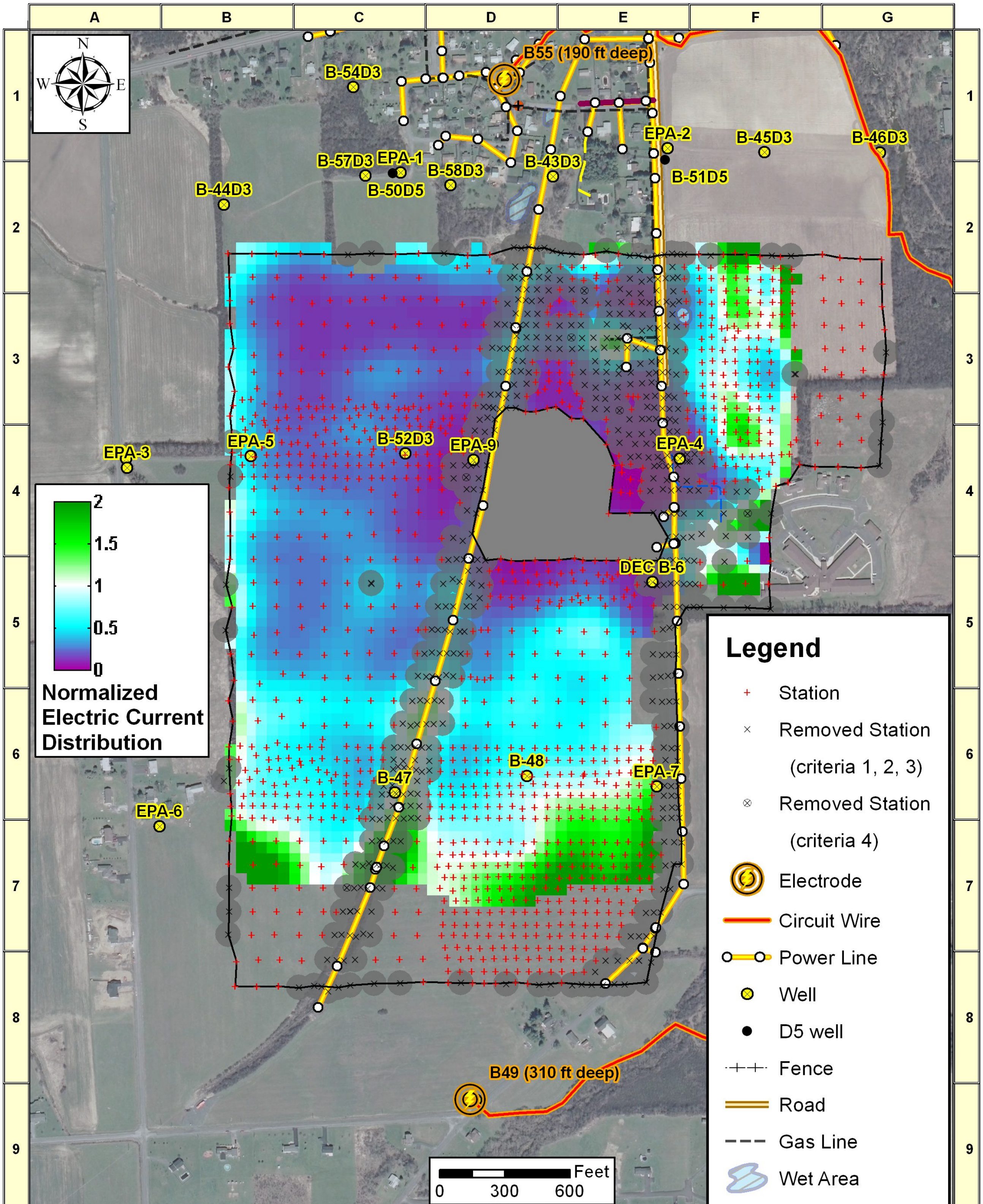
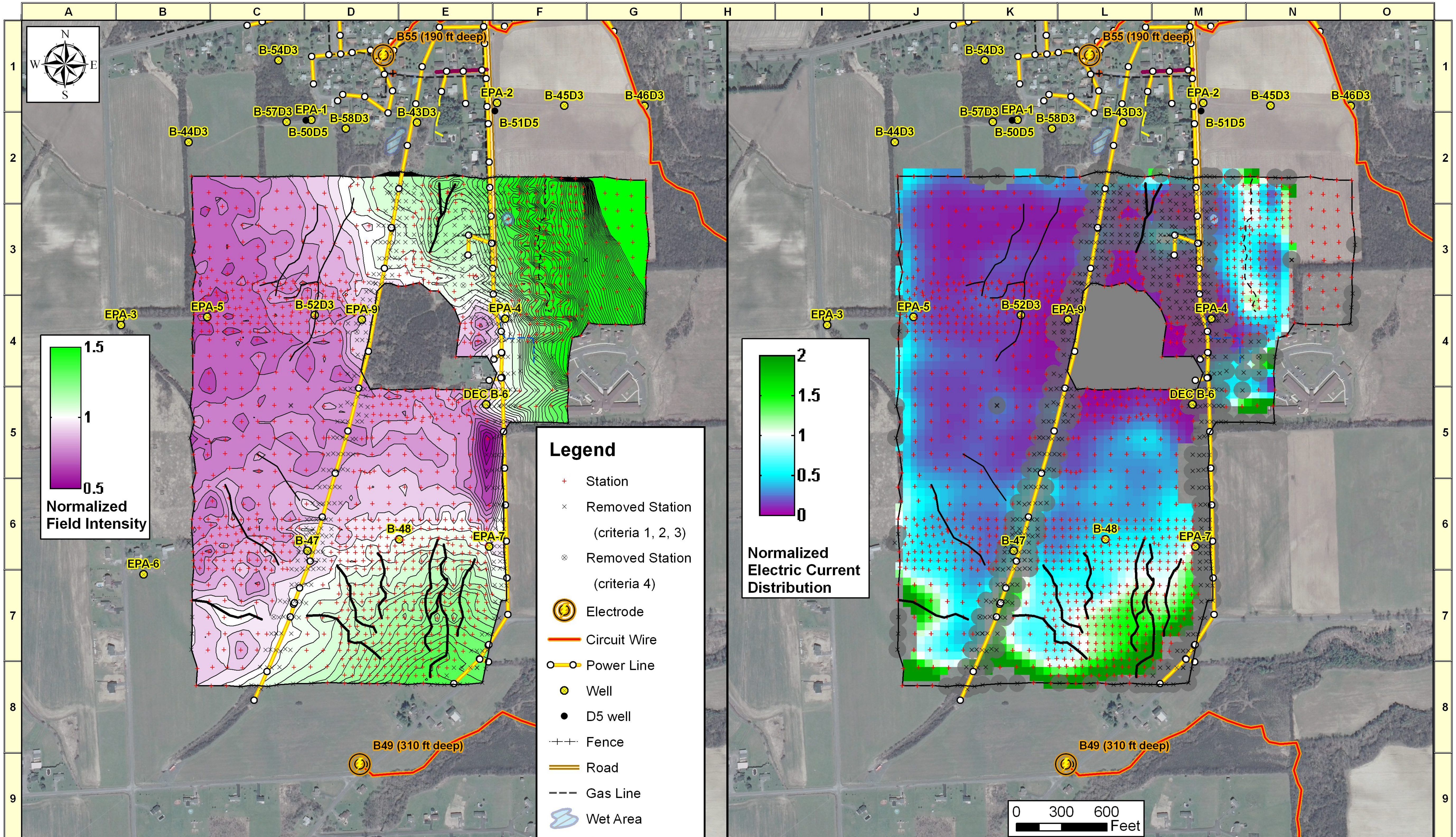


WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure 1.11 - ECD Model Slice Taken 20 Feet Below D3 Zone	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:7,200

R2-0025124



WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure 1.12 - Comparison of RR Map and ECD Model Slice in D3 Zone	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:7,200

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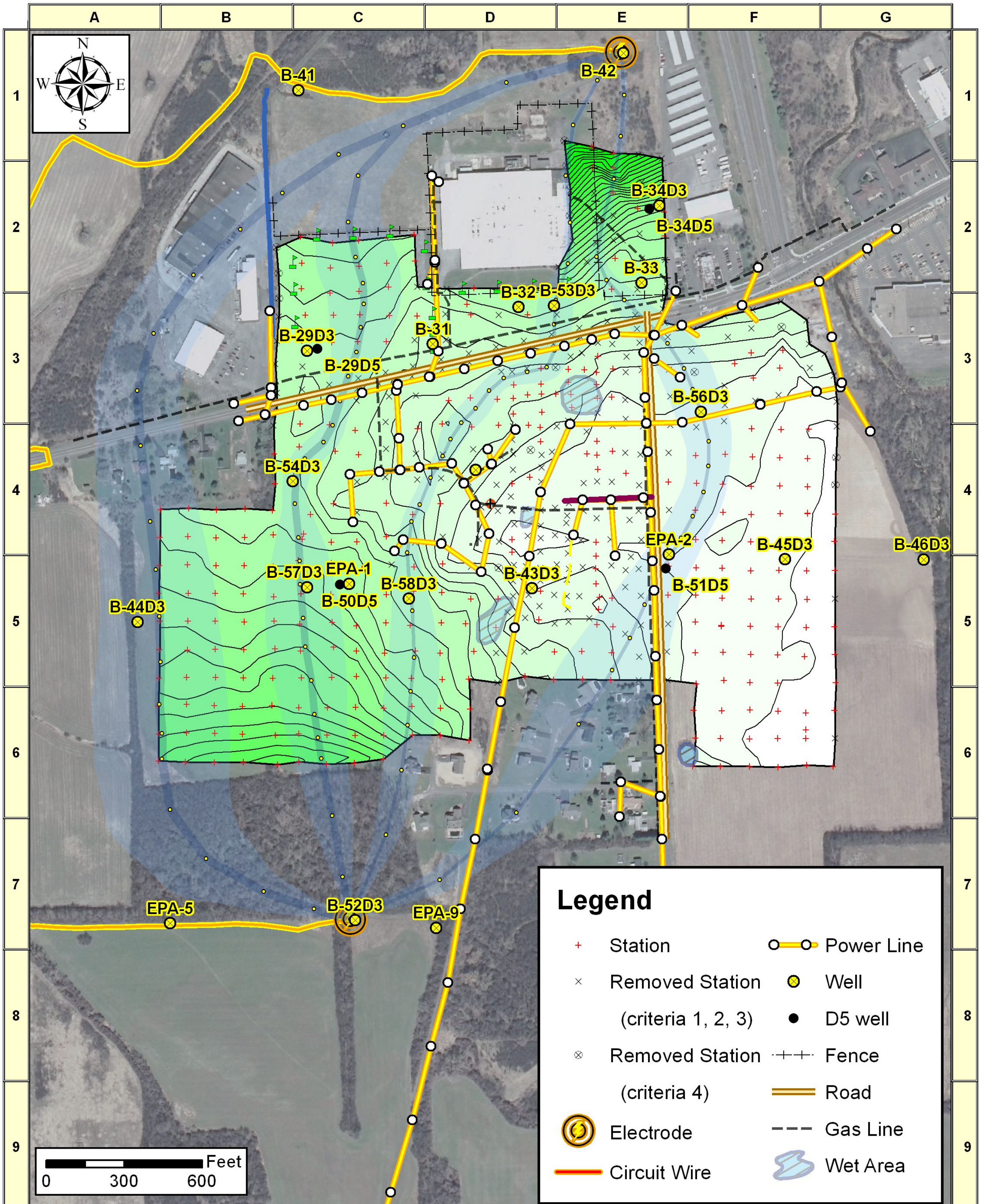
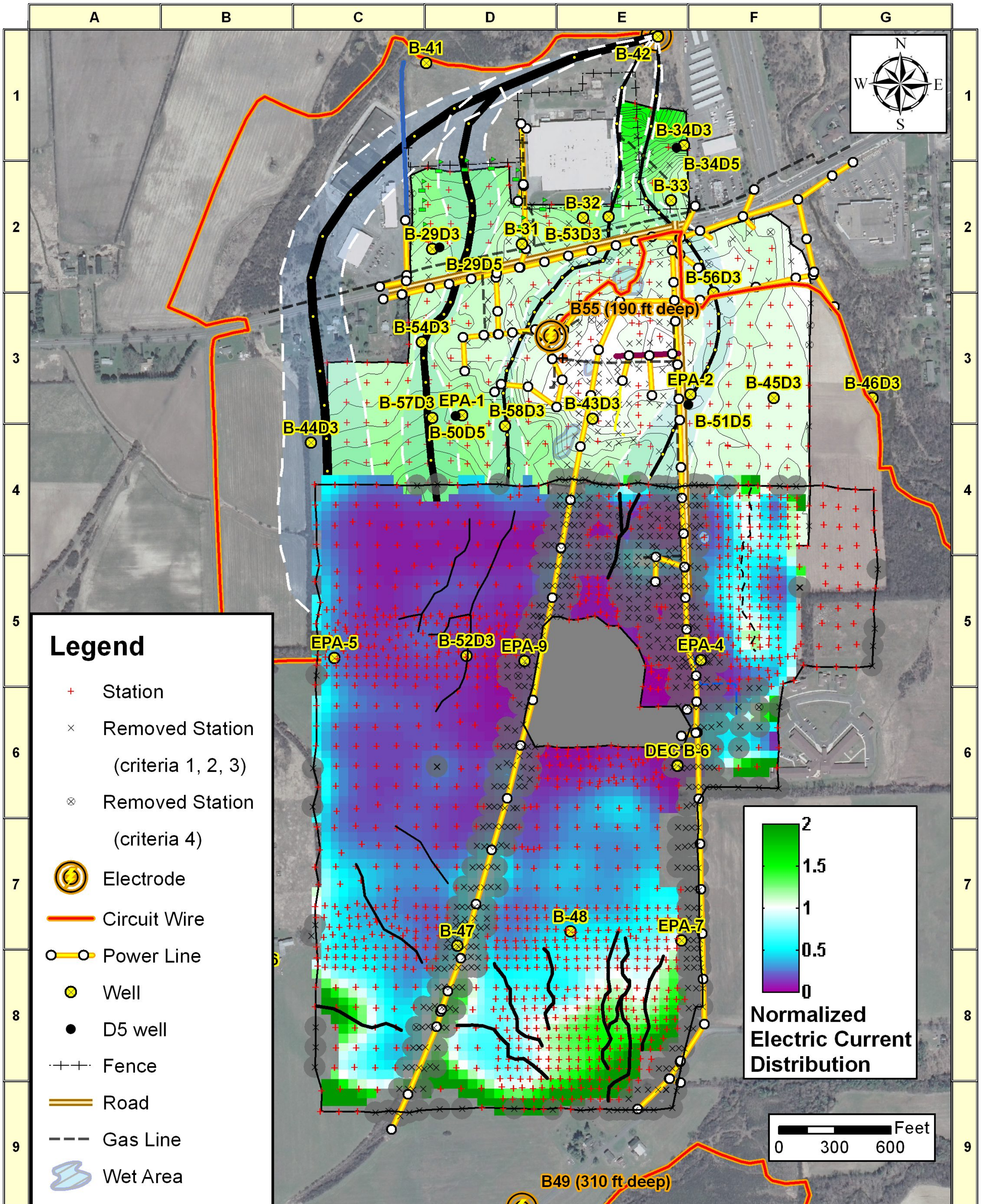


WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure 2.1 - Phase I Magnetic Field Map with ECF Paths	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:6,000

R2-0025126



WILLOWSTICK TECHNOLOGIES, LLC. Groundwater Mapping Services 11814 Election Road, Suite 100 Draper, Utah 84020 TEL: (801) 984-9850 FAX: (801) 984-9851	willowstick	AquaTrack Geophysical Investigation O'Brien & Gere - Auburn, NY Figure 2.2 - Comparison of Phase I and Phase II Models	PROJECT #: 10106 DATE: 29-July-2011 SCALE: 1:8,400

R2-0025127